U.S. Department
of Transportation
Federal Aviation Administration

Advisory Circular

Subject: Compliance of Transport Category Airplanes with Certification Requirements for Flight in Icing Conditions

Date: 10/27/14

Initiated By: ANM-110

AC No: 25-28

This advisory circular (AC) describes an acceptable means for showing compliance with the supercooled large drop condition requirements of § 25.773, *Pilot compartment view*, § 25.1323, *Airspeed indicating system*, § 25.1324, *Angle of attack system*, and § 25.1325, *Static pressure systems*, as well as the requirements of § 25.1419, *Ice protection*, and § 25.1420, *Supercooled large drop icing conditions*, of Title 14, Code of Federal Regulations (14 CFR) part 25. Part 25 contains the certification requirements for transport category airplanes. The compliance means described in this document are intended as guidance. They are meant to supplement the engineering judgment that must form the basis of any compliance findings for the supercooled large drop icing conditions in §§ 25.773, 25.1323, 25.1324, and 25.1325, as well as the compliance findings for §§ 25.1419 and 25.1420.

If you have suggestions for improving this AC, you may use the feedback form at the end of this AC.

Michael Kaszycki

Michael Kaszycki
Acting Manager, Transport Airplane Directorate
Aircraft Certification Service

Contents

Paragraph **Page**

Contents (continued)

Paragraph **Page**

Contents (continued)

Contents (continued)

Paragraph **Page**

Tables

1 PURPOSE.

1.1 This AC describes an acceptable means for showing compliance with the supercooled large drop condition requirements of § 25.773, Pilot compartment view, § 25.1323, Airspeed indicating system, § 25.1324, Angle of attack system, and § 25.1325, Static pressure systems, as well as the requirements of § 25.1419, Ice protection, and § 25.1420, Supercooled large drop icing conditions, of 14 CFR part 25. Part 25 contains the certification requirements for transport category airplanes. The compliance means described in this document are intended as guidance. They are meant to supplement the engineering judgment that must form the basis of any compliance findings for the supercooled large drop icing conditions in §§ 25.773, 25.1323, 25.1324, and 25.1325, as well as the compliance findings for §§ 25.1419 and 25.1420.

1.2 The following appendices appear at the end of this AC:

- Appendix A, *Related Regulations and Documents*.
- Appendix B, *History of Icing Certification Rules*.
- Appendix C, *Example of Certification to § 25.1420(a)(1) Using Visual Cues*.
- Appendix D, *Guidance for Amended Type Certificates and Supplemental Type Certificates*.
- Appendix E, *Capabilities of Engineering Tools for Compliance with Appendix O Requirements of Part 25*.
- Appendix F, *Acronyms*.

2 APPLICABILITY.

2.1 This AC provides guidance directed to airplane manufacturers, modifiers, foreign regulatory authorities, and Federal Aviation Administration (FAA) airplane type certification engineers and their designees. This guidance applies to certification of part 25 transport category airplanes for flight in icing conditions.

2.2 This material in this AC is neither mandatory nor regulatory in nature and does not constitute a regulation. It describes acceptable means, but not the only means, for demonstrating compliance with the applicable regulations. The FAA will consider other methods of demonstrating compliance that an applicant may elect to present. While these guidelines are not mandatory, they are derived from extensive FAA and industry experience. If, however, we become aware of circumstances that convince us that following this AC would not result in compliance with the applicable regulations, we will not be bound by the terms of this AC, and we may require additional substantiation or design changes as a basis for finding compliance.

2.3 This material in this AC does not change or create any additional regulatory requirements, nor does it authorize changes in, or permit deviations from, regulatory requirements.

2.4 The guidance provided in this AC applies to certification of part 25 transport category airplanes for flight in icing conditions. If certification for flight in icing conditions is desired, the airplane must be able to safely operate throughout the icing envelope defined in 14 CFR part 25, Appendix C. Additional icing requirements in part 25 apply to airplanes for which at least one of the following applies—

- The airplane's gross weight is less than 60,000 lbs, or
- The airplane is equipped with reversible flight controls.

2.5 Such an airplane, besides being able to operate safely in Appendix C icing conditions, must also be able to safely operate in or exit the icing conditions defined by 14 CFR part 25, Appendix O, Supercooled Large Drop Icing Conditions. The applicant, however, has several certification options available for Appendix O icing conditions. The airplane can be certified for—

2.5.1 The ability to detect Appendix O conditions and safely exit all icing conditions,

2.5.2 The ability to operate safely throughout a portion of Appendix O icing conditions and safely exit all icing conditions when that portion of Appendix O is exceeded, or

2.5.3 The ability to operate safely throughout all Appendix O icing conditions.

2.6 Sections 25.1419 and 25.1420 provide specific airframe requirements for certificating an airplane to operate in the icing conditions defined in Appendices C and O. Additionally, for other parts of the airplane (i.e., engine, engine inlet, propeller), there are more specific icing requirements and associated guidance. These are contained in the regulations and ACs listed in Appendix A of this AC. Some icing-related regulations must be complied with even if the airplane is not certificated for flight in icing. The following are examples:

- Section 25.629(d)(3).
- Section 25.903.
- Section 25.975.
- Section 25.1093.
- Section 25.1323(i).
- Section 25.1324.
- Section 25.1325(b).

2.7 This AC contains information on flight tests for ice protection certification. Additional information on flight tests for showing compliance with the airplane performance and handling qualities requirements for icing certification may be found in AC 25-25A, Performance and Handling Characteristics in Icing Conditions. AC 20-73A, Aircraft Ice Protection, also contains flight-in-icing approval guidance. The guidance in this AC is applicable to new type certificates (TCs), supplemental type certificates (STCs), and amendments to existing TCs for airplanes certified under part 4b of the Civil Air

Regulations (CAR) and under part 25, for which approval under the provisions of § 25.1419 is desired.

3 CANCELLATION.

This AC cancels AC 25.1419-1A, *Certification of Transport Category Airplanes for Flight in Icing Conditions*, dated May 7, 2004, and AC 25.1419-2, *Compliance with the Ice Protection Requirements of §§ 25.1419(e), (f), (g), and (h)*, dated October 27, 2009.

4 BACKGROUND.

Before 1953, airplanes were certificated under part 04 of the Civil Air Regulations (CARs). The first icing rule, section 04.5814, stated that if deicer boots were installed on an airplane, positive means for deflation of all wing boots was required. There were no other references to an airplane ice protection system (IPS) in part 04. Part 4b of the CAR was codified on December 31, 1953, and it was subsequently recodified into 14 CFR part 25, effective February 1, 1965. Over the years, as our knowledge has increased about icing conditions and their effects on safe operation of airplanes, we have made changes to the regulations. A detailed history of icing certification requirements can be found in Appendix B of this AC.

5 DEFINITION OF TERMS.

For purposes of this AC, the following definitions are used.

Note: These definitions of terms are intended for use only with respect to §§ 25.1419 and 25.1420.

5.1 Advisory Ice Detection System.

A system that advises the flightcrew of the presence of ice accretion or icing conditions. An advisory ice detection system can only be used in conjunction with other means (most commonly, visual observation by the flightcrew) to determine the need for, or timing of, activating the anti-icing or deicing system. When using an advisory ice detection system, the flightcrew is responsible for monitoring icing conditions or ice accretion as defined in the airplane flight manual (AFM), typically using total air temperature and visible moisture criteria or visible ice accretion. The flightcrew is responsible for activating the anti-icing or deicing system(s).

5.2 Airframe Icing.

Ice accretion on the airplane, except for on the propulsion system.

5.3 Anti-Icing.

Prevention of ice accretions on a protected surface either by evaporating the impinging water, or allowing the impinging water to run back and off the protected surface or freeze on non-critical areas.

5.4 **Appendix C Icing Conditions.**

The environmental conditions defined in Appendix C of 14 CFR part 25.

5.5 **Appendix O Icing Conditions.**

The environmental conditions defined in Appendix O of 14 CFR part 25.

5.6 **Artificial Ice.**

Real ice formed by artificial or simulated means, such as by a spray rig in a tunnel or behind an icing tanker.

5.7 **Automatic Cycling Mode.**

A mode of operation of the airframe deicing system that provides repetitive cycles of the system without the need for the pilot to select each cycle. This is generally done with a timer, and there may be more than one timing mode.

5.8 **Deicing.**

Removing or the process of removing an ice accretion after it has formed on a surface.

5.9 **Drizzle Drop.**

A drop of water measuring 100 to 500 micrometers, or microns (µm), (0.1 – 0.5 mm) in diameter.

5.10 **Freezing Drizzle (FZDZ).**

Supercooled drizzle drops that remain in liquid form and freeze on contact with objects colder than 0 °C.

5.11 **Freezing Precipitation.**

Any form of supercooled liquid precipitation that freezes on impact with the ground or exposed objects colder than 0 °C—freezing rain or freezing drizzle.

5.12 **Freezing Rain (FZRA).**

Supercooled rain drops that remain in liquid form and freeze on contact with objects colder than 0 °C.

5.13 **Glaciated Icing Conditions.**

Icing conditions in which only ice crystals are present.

5.14 **Ice Protection System (IPS).**

A system that protects certain critical airplane parts from ice accretion.

5.15 **Icing Conditions.**

The presence of atmospheric moisture and temperature conducive to airplane icing.

5.16 **Icing Conditions Detector.**

A device that detects the presence of atmospheric moisture and temperature conducive to airplane icing.

5.17 **Irreversible Flight Controls.**

Flight controls in the normal operating configuration that have force or motion originating at the airplane's control surface (through aerodynamic loads, static imbalance, or trim or servo tab inputs, for example) that is transmitted to the actuator and its mounting. The force or motion cannot be transmitted directly back to the flight deck controls. This term refers to flight controls in which all of the force necessary to move the pitch, roll, or yaw control surfaces is provided by hydraulic or electric actuators, the motion of which is controlled by signals from the flight deck controls.

5.18 **Liquid Water Content (LWC).**

The total mass of water contained in liquid drops within a unit volume of air, usually given in units of grams of water per cubic meter (g/m^3).

5.19 **Mean Effective Diameter (MED).**

The calculated drop diameter that divides the total liquid water content present in the drop size distribution in half. Half the water volume will be in larger drops and half the volume in smaller drops. This value is calculated, as opposed to measuring actual drop size. The MED is based on an assumed Langmuir drop size distribution. The fact that it is a calculated measurement is how it differs from median volume diameter, which is based on actual drop size.

5.20 **Median Mass Dimension (MMD).**

The particle size (sphere or equivalent mass) that divides the total ice mass present in an ice particle distribution in half. Half the ice mass is in larger particles and half the ice mass is in smaller particles.

5.21 **Median Volume Diameter (MVD).**

The drop diameter that divides the total liquid water content present in the drop distribution in half. Half the water volume will be in larger drops and half the volume in smaller drops. This value is obtained by actual drop size measurements.

5.22 **Migrating Ice.**

Ice resulting from the down-stream migration and build up of ice from wet protected surfaces to areas that cool sufficiently for the migrating ice to adhere to the surface.

5.23 **Mixed Phase Icing Conditions.**

Icing conditions in which both ice crystals and supercooled liquid water drops are present.

5.24 Monitored Surface.

The surface of concern regarding the ice hazard (for example, the leading edge of a wing). Ice accretion on the monitored surface may be measured directly or correlated to ice accretion on a reference surface.

5.25 Primary Ice Detection System.

A detection system used to determine when the IPS must be activated. This system announces the presence of ice accretion or icing conditions, and it may also provide information to other airplane systems. A primary *automatic* system automatically activates the anti-icing or deicing IPS. A primary *manual* system requires the flightcrew to activate the anti-icing or deicing IPS on indication from the primary ice detection system.

5.26 Rain Drop.

A drop of water greater than 500 µm (0.5 mm) in diameter.

5.27 Reference Surface.

The observed surface used as a reference for the presence of ice on the monitored surface. The reference surface may be observed directly or indirectly. Ice must occur on the reference surface before—or at the same time—it appears on the monitored surface. Examples of reference surfaces include windshield wiper blades or bolts, windshield posts, ice evidence probes, the propeller spinner, and the surface of ice detectors. The reference surface may also be the monitored surface.

5.28 Reversible Flight Controls.

Flight controls in the normal operating configuration that have force or motion originating at the airplane's control surface (through aerodynamic loads, static imbalance, or trim or servo tab inputs, for example) that is transmitted back to flight deck controls. This term refers to flight deck controls connected to the pitch, roll, or yaw control surfaces by direct mechanical linkages, cables, or push-pull rods in such a way that pilot effort produces motion or force about the hinge line.

5.28.1 Aerodynamically Boosted Flight Controls.

Reversible flight control systems that employ a movable tab on the trailing edge of the main control surface linked to the pilot's controls or to the structure in such a way as to produce aerodynamic forces that move, or help to move, the surface. Among the various forms are flying tabs, geared or servo tabs, and spring tabs.

5.28.2 Power-Assisted Flight Controls.

Reversible flight control systems in which some means is provided, usually a hydraulic actuator, to apply force to a control surface in addition to that supplied by the pilot to enable large surface deflections to be obtained at high speeds.

5.29 Runback Ice.

Ice formed from the freezing or refreezing of water leaving one area on an airplane surface that is above freezing temperature and flowing downwind to another area that is sufficiently cooled for freezing (or refreezing) to take place. This ice type is frequently an unwanted product of thermal deicing systems.

5.30 **Simulated Ice.**

Ice shapes fabricated from wood, epoxy, or other materials by any construction technique.

5.31 **Static Air Temperature.**

The air temperature that would be measured by a temperature sensor that is not in motion in relation to that air. This temperature is also referred to in other documents as "outside air temperature," "true outside temperature," or "ambient temperature."

5.32 **Substantiated Visual Cue.**

Ice accretion on the airplane's protected surface or on a reference surface that has been demonstrated by testing to correlate with ice accretion on a monitored surface.

5.33 **Supercooled Large Drops (SLD).**

Supercooled liquid water that includes freezing rain or freezing drizzle.

5.34 **Supercooled Water.**

Liquid water at a temperature below the freezing point of 0 °C.

5.35 **Water Catch.**

The amount of water that strikes an airplane surface.

6 ICING ENVELOPES.

6.1 The Appendix O Environment.

6.1.1 The conditions included in the part 25, Appendix C, icing envelopes are unchanged by the addition of Appendix O. For details on the Appendix C icing envelopes, see AC 20-73A, *Aircraft Ice Protection*, and FAA Technical Report DOT/FAA/CT-88/8-1, *Aircraft Icing Handbook.* Appendix O was developed to define a representative icing environment for supercooled large drops. Supercooled large drops, which include freezing drizzle and freezing rain conditions, are not included in Appendix C.

6.1.2 Section 25.1420 requires that the airplane operate safely in the supercooled large drop icing conditions defined in part 25, Appendix O. This section is applicable to airplanes for which either of the following applies—

6.1.2.1 The airplane's maximum gross weight is less than 60,000 pounds, or

6.1.2.2 The airplane is equipped with reversible flight controls.

6.1.3 Section 25.1420 requires compliance with § 25.1420(a)(1), (a)(2), or (a)(3). When complying with § 25.1420(a)(1), the applicant must provide a method for detecting that the airplane is operating in Appendix O icing conditions. Following detection, the airplane must be capable of operating safely while exiting all icing conditions. If the applicant seeks certification for safe operation in portions of Appendix O conditions, such as freezing drizzle only, or during specific phases of flight, § 25.1420(a)(2) applies. If this option is chosen, following detection of conditions that exceed the selected portion of Appendix O, the airplane must be capable of operating safely while exiting all icing conditions. Certification for a portion of Appendix O (§ 25.1420(a)(2)) or none of Appendix O (§ 25.1420(a)(1)) requires substantiated methods of alerting the flightcrew when those portions of Appendix O are exceeded (§ 25.1420(a)(2)) or when Appendix O conditions are encountered (§ 25.1420(a)(1)). Section 25.1420(a)(3) applies when the applicant seeks certification for all of the icing conditions described in Appendix O. An airplane certified to § 25.1420(a)(3) must be capable of safely operating throughout the conditions described in Appendix O and does not need a means to detect Appendix O conditions. In effect, when § 25.1420(a)(3) is chosen, the airplane is certificated for flight in icing without any specific AFM procedures or limitations to exit icing conditions.

Note: While this AC provides guidance for compliance with § 25.1420(a)(2), further advancements in engineering tools may be necessary before an applicant is able to substantiate compliance with this option. A 2009 review of engineering tool capabilities found that current technology does not support distinguishing between freezing drizzle and freezing rain in flight. Therefore, certification for a portion of Appendix O will be challenging and will require close coordination with certifying authorities. Consult Appendix E of this AC for additional details on engineering tool capabilities.

6.1.4 Appendix O defines freezing drizzle and freezing rain environments by using four spectra of drop sizes with associated liquid water content (LWC) limits. An FAA detailed report on the development of Appendix O is available from the FAA William J. Hughes Technical Center (see FAA Technical Report DOT/FAA/AR-09/10, *Data and Analysis for the Development of an Engineering Standard for Supercooled Large Drop Conditions*, dated March 2009). Following are the four drop size spectra:

6.1.4.1 Freezing drizzle environment with a median volume diameter (MVD) less than 40 microns (µm). In addition to drizzle drops, which are defined as measuring 100 µm to 500 µm in diameter, this environment contains drops less than 100 µm, with a sufficient number of drops less than 40 µm so the MVD is less than 40 µm.

6.1.4.2 Freezing drizzle environment with an MVD greater than 40 µm. In addition to freezing drizzle drops, this environment contains smaller drops, with diameters less than 100 µm.

6.1.4.3 Freezing rain environment with an MVD less than 40 µm. In addition to freezing rain drops, which are defined as measuring more than 500 µm in diameter, this environment also contains smaller drops of less than 500 µm with a sufficient number of drops less than 40 µm so the MVD is less than 40 µm.

6.1.4.4 Freezing rain environment with an MVD greater than 40 µm. In addition to freezing rain drops, this environment also contains smaller drops of less than 100 µm.

6.1.5 Initial certification for flight in a portion of Appendix O conditions will likely include all of freezing drizzle or all of freezing rain. Such certification could be restricted to operation in Appendix O conditions by phase of flight. Certification for flight in a portion of Appendix O conditions depends on the applicant substantiating an acceptable way for the flightcrew to distinguish the portion of Appendix O conditions for which the airplane is certified from the portion of Appendix O conditions for which the airplane is not approved. Certification for a portion of Appendix O allows latitude for certification with a range of techniques. Ice shapes will need to be developed to test for the portion of the envelope for which the airplane is approved, as well as for detecting and exiting icing conditions beyond the selected portion.

6.1.6 Ice shapes developed using the approved portion of the icing envelope should account for the range of drop distribution and water content and consider the proposed method for identifying icing conditions that must be exited. The definition of the certificated portion of Appendix O for a particular airplane should be based on measured characteristics of the selected icing environment and be consistent with methods used for developing Appendix O.

6.1.7 Water content versus drop size relationships defined in Appendix C, figures 1 and 4, are defined in terms of mean effective diameter. Part 25 does not require consideration of specific distributions for Appendix C icing conditions. As referenced in FAA Technical Report DOT/FAA/CT-88/8-1 and AC 20-73A, single mode distributions such as Langmuir distributions have been used to represent the range of drop sizes and water content associated with a specific Appendix C icing condition.

6.1.8 The distributions assumed for Appendix C icing conditions are not appropriate for freezing precipitation icing conditions. This is because these icing conditions often consist of small and large drops that are bi-modally distributed. Langmuir type distributions cannot capture the bi-modal characteristic. Consequently, distributions of drop sizes are defined as part of Appendix O. The need to include distributions comes from the fact that a larger percentage of the cloud’s total water mass is contained in the larger diameter drops of Appendix O. The water mass of larger drops affects the water catch on airplane components. It also affects drop impingement, icing limits, and the ice build-up shape. Ice accretions resulting from the water catch must be considered for their effects on safe flight of the airplane.

6.1.9 Liquid water content maximum values for freezing drizzle and freezing rain decrease as temperature decreases. This is defined in Appendix O, figures 1 and 4, respectively. Appendix O values of total liquid water follow the same standard as those in Appendix C. They represent liquid water content for a horizontal extent distance of 17.4 nautical miles (20 statute miles).

6.1.10 The maximum vertical extent distance of 12,000 feet for freezing drizzle includes the cloud layer and all drizzle precipitation below the cloud that is within 12,000 feet of the cloud top. The maximum altitude of freezing drizzle is the same as that for an Appendix C continuous maximum icing cloud—22,000 feet (Appendix O, figure 3). Temperatures range to as low as -13 °F (-25 °C).

6.1.11 The maximum vertical extent distance for freezing rain is 7,000 feet. The maximum altitude of freezing rain is 12,000 feet. Temperatures range to as low as 8.6 °F (-13 °C).

6.1.12 It is not appropriate to use the United States Standard Atmosphere Temperature Lapse Rate with Altitude for freezing drizzle and freezing rain. Typically, freezing rain is associated with temperature inversions. Freezing drizzle is associated with other deviations from the standard lapse rate. When generating ice shapes associated with vertical transits through freezing drizzle and freezing rain, the critical temperature should be determined and used for the duration of the vertical exposure.

6.1.13 Liquid water content of continuous freezing drizzle and freezing rain decreases as the length of the precipitation area, or its horizontal extent, increases. The horizontal extent of an airplane's exposure to freezing drizzle and freezing rain can be anywhere from a brief encounter to an extended one. An "f-factor" is used in Appendix O to calculate liquid water content per cubic meter based on the length of the cloud (its horizontal extent). The f-factor used in Appendix O is the same as is used in Appendix C for these calculations. This f-factor is discussed in appendix N of AC 20-73A.

6.2 **Use of Icing Envelopes.**

6.2.1 AC 20-73A addresses the use of Appendix C. Use of Appendix C is not changed by the addition of Appendix O. Appendix O is designed to be similar to Appendix C and to be used in much the same manner. The principal differences between using Appendix O and using Appendix C are that for Appendix O, the applicant must now—

6.2.1.1 Consider four icing conditions rather than two when determining critical icing conditions, and

6.2.1.2 Address drop size distributions.

6.2.2 Applications of drop size distributions typically require a bin tabulation of the proportion of mass (liquid water content) to drop diameter. Table 1 and table 2, which follow, represent 10-bin tabulations for the cumulative distributions in Appendix O. Mass proportions for the bins were selected to provide a reasonable resolution of the upper range of the distributions. The shaded columns (a) and (b) in the tables contain values typically used as input to ice accretion computer codes. For some simulation techniques, different methods of segregating the bins may be appropriate.

Table 1. Freezing Drizzle Drop Size Distributions Represented Using 10 Bins

		Freezing Drizzle Environment with MVD<40 µm			Freezing Drizzle Environment with MVD>40 µm		
	(a)		(b)			(b)	
Bin	**Proportion of Mass**	**Left Boundary Point (µm)**	**Mass-Weighted Midpoint (µm)**	**Right Boundary Point (µm)**	**Left Boundary Point (µm)**	**Mass-Weighted Midpoint (µm)**	**Right Boundary Point (µm)**
1	0.100	1	9	10	1	11	15
2	0.200	10	13	16	15	22	36
3	0.200	16	18	20	36	64	106
4	0.200	20	23	27	106	150	197
5	0.100	27	29	33	197	221	247
6	0.050	33	36	40	247	261	276
7	0.050	40	48	66	276	292	309
8	0.050	66	97	137	309	330	354
9	0.025	137	163	202	354	370	390
10	0.025	202	252	388	390	417	473

Note: Drop size distributions in one-micron-drop bin resolution are available in electronic files from the William J. Hughes Technical Center.

Table 2. Freezing Rain Drop Size Distributions Represented Using 10 Bins

		Freezing Rain Environment with MVD < 40 µm			Freezing Rain Environment with MVD > 40 µm		
	(a)		(b)			(b)	
Bin	**Proportion of Mass**	**Left Boundary Point (µm)**	**Mass-Weighted Midpoint (µm)**	**Right Boundary Point (µm)**	**Left Boundary Point (µm)**	**Mass-Weighted Midpoint (µm)**	**Right Boundary Point (µm)**
1	0.100	1	7	8	1	9	14
2	0.200	8	10	12	14	35	236
3	0.200	12	15	19	236	399	526
4	0.200	19	25	53	526	645	765
5	0.100	53	255	468	765	833	912
6	0.050	468	534	595	912	957	1008
7	0.050	595	655	718	1008	1066	1129
8	0.050	718	792	883	1129	1197	1288
9	0.025	883	942	1034	1288	1345	1420
10	0.025	1034	1191	1553	1420	1545	2228

Note: Drop size distributions in one-micron-drop bin resolution are available in electronic files from the William J. Hughes Technical Center.

6.2.3 When compared with the Langmuir distributions of drop sizes commonly associated with Appendix C clouds, Appendix O drop size distributions have much larger drop sizes and a larger percentage of the total water mass in large drop sizes. The liquid water contents associated with icing conditions in Appendix O are different from those associated with Appendix C. These differences may affect water collection efficiency. They may result in impingement limits that are further aft for Appendix O icing conditions than they are for Appendix C icing conditions. For more discussion of the effects of drop size and trajectory influence, see FAA Technical Report DOT/FAA/CT-88/8-1 and AC 20-73A.

6.2.4 An additional effect of the supercooled large drop environment is the variability in distribution of drop sizes. Ice shapes developed to simulate Appendix C icing conditions are sometimes calculated by using a monodispersed drop distribution. This is because predicted main ice shapes are not highly sensitive to commonly assumed distributions for Appendix C (such as the Langmuir distributions). In a monodispersed drop distribution, all drop diameters are assumed to be equal to the MVD. The large variations of drop size and the larger percentages of water in the larger drops defined by Appendix O tend to magnify effects of distributed drop sizes. This may be reflected in the main ice shape and in runback ice characteristics.

7 CERTIFICATION PLAN.

At the start of the design and development of an airplane, the applicant should submit a certification plan that addresses the IPS to the appropriate FAA aircraft certification office (ACO) for approval. This certification plan should include the following basic information:

7.1 A general description of the airplane that includes dimensions, airworthiness limitations, and other data that may be relevant to the airplane's IPS.

7.2 Description of the IPS.

7.3 A compliance checklist addressing each section of part 25 applicable to the IPS.

7.4 Identification of the certification methods for each applicable section of part 25, including a description of analyses and tests or references to similarity of designs, that the applicant intends to use for certifying the IPS. The applicant and the FAA should agree on these compliance means early in the certification program and before certification testing begins.

7.5 A failure hazard assessment to determine the criticality of the system.

7.6 If the ice protection or detection system contains software, software plans as described in Radio Technical Commission for Aeronautics (RTCA) DO-178C, Software Considerations in Airborne Systems and Equipment Certification (or another acceptable means of compliance for software).

7.7 Projected schedules of design, analyses, testing, and reporting.

7.8 A list of any anomalous results from completed icing certification tests (relevant to the requirements of 14 CFR 33.68 and 33.77) that will require special operating procedures unless this information is provided in a separate certification document or other airworthiness approved documentation.

7.9 If the IPS or icing detection system contains complex electronic hardware (such as programmable logic devices or application-specific integrated circuits), plans for providing a level of design assurance for these devices commensurate with their potential contribution to airplane hazards and system failures. Such hazards or failures could result from electronic hardware faults or malfunctions. The applicant should consult RTCA DO-254, Design Assurance Guidance for Airborne Electronic Hardware, and RTCA DO-160G, Environmental Conditions and Test Procedures for Airborne Equipment, on how to provide design assurance for these devices.

8 ANALYSIS.

The applicant should prepare analyses to substantiate the choice of ice protection equipment for the airplane. Such analyses should clearly state the basic protection required and assumptions made, and delineate the methods of analysis used. All analyses should be validated by tests or should have been validated by the applicant on a previous certification program. The applicant who uses a previously validated method should substantiate why that method is applicable to the new program.

8.1 Analytical Simulation Methods.

Analytical simulation methods for icing include impingement and accretion models based on computational fluid dynamics (CFD). The applicant will typically use these methods to evaluate protected as well as unprotected areas for potential ice accretions. Analytical simulation provides a way to account for the variability in drop distributions. It also makes it possible to examine impingement in relation to visual icing cues and to analyze the location of detection devices for detrimental local flow effects.

8.2 Substantiating Icing Simulation Analytical Tools.

8.2.1 The substantiation process for icing simulation analytical tools, such as icing codes and cross comparisons, should be made with data derived from using other types of tools to show that the analytical simulation results are equivalent or conservative. Other types of test data that the icing simulation analytical tool data could be compared with are:

- Natural icing flight test data.
- Tanker test data.
- Icing tunnel data.
- Icing tunnel data.

8.2.2 Results of analysis with icing codes, as well as results of icing tunnel tests and tanker tests, should be compared to results of natural icing flight tests in Appendix C conditions that are required by § 25.1419. Engineering judgment is required when evaluating these comparisons because most simulation tools are steady-state simulations and they will be compared with tests made in natural icing conditions, which are variable. See AC 20-73A for additional guidance about substantiating icing simulation tools. The guidance in this paragraph applies to airframe, engine, and propeller icing tools for Appendix C and the applicable portion of Appendix O.

8.3 Analysis of Areas and Components to be Protected.

In evaluating the airplane's ability to operate safely in Appendix C icing conditions and relevant icing conditions of Appendix O, and in determining which components will be protected, the applicant should examine those areas listed in AC 20-73A to determine the degree of protection required. An applicant may determine that protection is not required for one or more of these areas or components. If so, the applicant's analysis should include the supporting data and rationale for allowing those areas or components to remain unprotected. The applicant should show that the lack of protection does not adversely affect handling characteristics or performance of the airplane, as required by § 25.21(g). The applicant must also show that the lack of protection does not affect the operation and functioning of affected systems and equipment (e.g., pitot probes). Accessory cooling air intakes that face the airstream could become restricted with ice accretion. Inlets (including National Advisory Committee for Aeronautics (NACA) inlets) that do not accrete ice in Appendix C conditions may accrete ice in Appendix O conditions.

8.4 **Flutter Analysis.**

AC 25.629-1B, *Aeroelastic Stability Substantiation of Transport Category Airplanes*, provides guidance for showing compliance with § 25.629. For airplanes approved for operation in icing conditions, that AC addresses nominal configurations with ice accumulations on unprotected surfaces as well as ice accumulations resulting from any single failure in the deicing system or any combination of failures not shown to be extremely improbable. AC 25.629-1B also provides guidance for consideration of inadvertent encounters with icing for airplanes not certificated for flight in icing conditions, as required by § 25.629(d)(3). Flutter analyses should reflect all mass accumulations of ice on protected and unprotected surfaces from exposure to Appendix C and Appendix O conditions in accordance with the guidance in AC 25.629-1B. This includes any accretions that could develop on control surfaces.

8.5 **Power Sources.**

The applicant should evaluate the power sources in the IPS design (e.g., electrical, bleed air, and pneumatic sources). An electrical load analysis or test should be conducted on each power source to determine that it is adequate to operate the IPS as well as to supply all other essential electrical loads for the airplane throughout the airplane flight envelope. The effect of an IPS component failure on availability of power to other essential loads should be evaluated in accordance with § 25.1309. All power sources affecting engines or engine IPSs for multi-engine airplanes must comply with the engine isolation requirements of § 25.903(b).

8.6 **Failure Analyses.**

8.6.1 Failure Analysis for § 25.1419 (Appendix C Conditions).

AC 25.1309-1A, *System Design Analysis*, provides guidance for demonstrating compliance with § 25.1309. The hazard classifications of IPS failure conditions are typically substantiated with analyses and/or testing. A failure analysis should include the potential contribution of complex electronic hardware faults and malfunctions to system failure conditions. It should also classify the hardware assurance level appropriately, as outlined in RTCA DO-254, *Design Assurance Guidance for Airborne Electronic Hardware*. For purposes of a quantitative analysis, the probability of encountering Appendix C icing conditions is considered "1."

8.6.2 Failure Analysis for § 25.1420 (Appendix O Conditions).

Applying the system safety principles of § 25.1309 is helpful in determining the need for system requirements to address potential hazards from an Appendix O icing environment. The following addresses application of the § 25.1309 principles to Appendix O conditions and may be used for showing compliance with § 25.1309.

8.6.2.1 Hazard Classification.

8.6.2.1.1 Assessing a hazard classification for compliance with § 25.1309 is typically a process combining quantitative and qualitative factors. If the design is new and novel and has little similarity to previous designs, a hazard classification based on past experience may not be appropriate. If the new design is derivative in nature, the assessment can consider the icing event history of similarly designed airplanes, and, if applicable, the icing event histories of all conventionally designed airplanes. The applicant should consider specific effects of supercooled large drop icing when assessing similarity to previous designs (see paragraph 12.1.4, *Some Areas of Interest for Appendix O*).

8.6.2.1.2 Qualitative analysis may be used to determine the hazard classification for an unannunciated encounter with Appendix O icing conditions. The analysis can be applied to airplanes shown to be similar to previous designs with respect to Appendix O icing effects, and to which the icing event histories of all conventionally designed airplanes are applicable. The following assumptions may be used to support the qualitative analysis:

8.6.2.1.2.1 The airplane is certificated to either detect Appendix O icing conditions and safely exit all icing after detection of Appendix O icing conditions, or safely operate in a selected portion of Appendix O icing conditions and safely exit all icing after detection of Appendix O icing conditions beyond those for which it is certificated.

8.6.2.1.2.2 The unannunciated encounter is with Appendix O icing conditions in which the airplane has not been shown to operate safely.

8.6.2.1.2.3 The airframe and propulsion IPSs have been activated prior to the unannunciated encounter.

8.6.2.1.3 The applicant may use service history, design, and installation appraisals to support hazard classifications for § 25.1309. Service history may be appropriate to support a hazard classification if a new or derivative airplane has similar design features to a previously certificated airplane.

8.6.2.1.4 While definitive statistics are not available, a historical perspective can provide some guidance. Many airplanes flying through icing have been exposed to supercooled large drop conditions without the pilot being aware of it. The interval of exposure to the supercooled large drop conditions may have varied from a brief amount of time (such as could occur during a vertical transition through a cloud) to a more sustained exposure (such as during a hold). Severity of the exposure conditions in terms of water content may have varied significantly. Therefore, not all encounters with supercooled large drop conditions will result in a catastrophic event.

8.6.2.1.5 Icing event history of conventionally designed airplanes certificated before the introduction of § 25.1420. Given the volume of airplane operations and the number of reported incidents that did not result in a catastrophe, a factor of around 1 in 100 is a reasonable assumption of probability for a catastrophic event if an airplane encounters Appendix O conditions in which it has not been shown capable of safely operating. An applicant may assume that the hazard classification is severe major for an unannunciated encounter with Appendix O conditions while the IPS is activated, in accordance with AC 25.1309-1A, provided that both of the following are true: (1) the airplane is similar to previous designs with respect to Appendix O icing effects, and (2) the applicant can show that the icing event history of all conventionally designed airplanes is relevant to the airplane being considered for certification

8.6.2.1.6 If an airplane is not similar to a previous design, an assessment of the hazard classification may require more analysis or testing. One method of hazard assessment would be to consider effects of ice accumulations similar to those expected for airplanes being certified under § 25.1420. Such ice shapes may be defined from a combination of analysis and icing tanker or icing wind tunnel testing. Aerodynamic effects of such shapes could be evaluated with wind tunnel testing or, potentially, CFD. See AC 20-73A for additional guidance on assessing aerodynamic effects of ice build-ups. Hazard classification typically takes place early in a certification program. Therefore, a conservative assessment may be required until sufficient supporting data is available to reduce the hazard classification.

8.6.2.2 Probability of Encountering Appendix O Conditions.

Appendix C was designed to include 99 percent of icing conditions. Therefore, the probability of encountering icing outside of Appendix C drop conditions is on the order of 10^{-2}. The applicant may assume that the average probability for encountering Appendix O icing conditions is 1 x 10^{-2} per flight hour. This probability should not be reduced based on phase of flight.

8.6.2.3 Numerical Safety Analysis.

For the purposes of a numerical safety analysis, the applicant may combine the probability of equipment failure with the probability, defined above, of encountering Appendix O icing conditions. If the applicant can support a hazard level of "hazardous," using the above probability (10^{-2})

of encountering the specified supercooled large drop conditions, the probability of an unannunciated failure of the equipment that alerts the flightcrew to exit icing conditions should be less than 1 x 10^{-5}.

8.6.2.4 Assessment of Visual Cues.

Typical system safety analyses do not address the probability of flightcrew actions, such as observing a visual cue before performing a specified action. As advised in AC 25.1309-1A, quantitative assessments of flightcrew errors are not considered feasible. When visual cues are to be the method for detecting Appendix O conditions and determining when to exit them, the applicant should assess the appropriateness and reasonableness of the specific cues (see paragraph 12.1.3.2 of this AC for additional guidance). Reasonable tasks are those for which the applicant can take full credit because the tasks can realistically be anticipated to be performed correctly when required. The applicant should assess the task of visually detecting Appendix O conditions to determine if it could be performed when required. The workload for visually detecting icing conditions should be considered in combination with the operational workload during applicable phases of flight. The applicant may assume that the flightcrew is already aware that the airplane has encountered icing. The assessment of whether the task is appropriate and reasonable is limited to assessing the task of identifying Appendix O accumulations that require exiting from the icing conditions.

8.7 **Similarity Analyses.**

8.7.1 For certification based on similarity to other type-certificated airplanes previously approved for flight in icing conditions, the applicant should specify the airplane model and the component to which the reference of similarity applies. The applicant should show specific similarities in the areas of physical, functional, thermodynamic, pneumatic, and aerodynamic characteristics as well as in environmental exposure. The applicant should conduct analyses to show that component installation, operation, and effect on the airplane’s performance and handling are equivalent to that of the same or similar component in the previously approved configuration.

8.7.2 A demonstration of similarity requires an evaluation of both system and installation differences. Differences should be evaluated for their effect on IPS functionality and on safe flight in icing. If there is uncertainty about the effects of the differences, the applicant should conduct additional tests and/or analyses as necessary and appropriate to resolve the open issues.

8.7.3 Section 25.1419(b) requires flight testing in measured natural icing conditions. Flight test data from previous certification programs may be used to show compliance with § 25.1419(b) if the applicant can show that the data is applicable to the airplane in question. If there is uncertainty about the similarity analysis, the applicant should conduct flight tests in measured natural icing conditions for compliance with § 25.1419(b).

8.7.4 On derivative or new airplane designs, the applicant can use similarity to previous type designs shown to comply with § 25.1420 or airplanes that have shown compliance with § 25.1419 that have a successful service history, if the effects of differences are substantiated. Natural ice flight testing may not be necessary for a design shown to be similar. At a minimum, the following differences should be addressed:

- Airfoil size, shape, and angle of attack.
- IPS design.
- Operating altitude and airspeed.
- Center of gravity.
- Flight control system.
- Engine and propeller operation.

Note: The applicant must possess all the data to substantiate compliance with applicable regulations, including data from past certifications on which the similarity analysis is based.

8.8 **Impingement Limit Analyses.**

8.8.1 The applicant should prepare a drop trajectory and impingement analysis of—

- Wings,
- Horizontal and vertical stabilizers,
- Propellers, and
- All other critical surfaces on which ice may accrete.

8.8.2 This analysis should consider the various airplane operational configurations, phases of flight, and associated angles of attack. The analysis should establish upper and lower aft drop impingement limits that can then be used to establish the aft ice formation limit and its relationship to the IPS coverage.

8.9 **Ice Shedding Analyses.**

8.9.1 Airframe ice shedding may damage or erode engine or powerplant components as well as lifting, stabilizing, and flight control surface leading edges. Fan and compressor blades, impeller vanes, inlet screens and ducts, and propellers are examples of powerplant components subject to damage from shedding ice. For fuselage-mounted turbojet engines (and pusher propellers that are very close to the fuselage and well aft of the airplane’s nose), ice shedding from the forward fuselage and from the wings may cause significant damage. Ice shedding from components of the airplane, including antennas, should not cause damage to engines and propellers that would adversely affect engine operation or cause serious loss of power or thrust (compliance with § 25.1093). The applicant should also consider airplane damage that can be caused by ice shedding from the propellers.

8.9.2 Control surfaces such as elevators, ailerons, flaps, and spoilers, especially those constructed of thin metallic, nonmetallic, or composite materials, are also subject to damage. Currently available trajectory and impingement analyses may not adequately predict such damage. Unpredictable ice shedding paths from forward areas such as radomes and forward wings (canards) have been found to negate the results of these analyses. For this reason, a damage analysis should consider that the most critical ice shapes will shed and impact the areas of concern. For analysis of the radome as a potential airframe ice source, the applicant may use qualitative analysis of the design supported by similarity to previous design that has shown successful service history to have confidence that the historical methodology for certification represented by *Table 1—Minimum Ice Slab Dimensions Based on Engine Inlet Size* of § 33.77 is appropriate.

8.10 **Propeller Deicing Analysis.**

The applicant should perform a propeller deicing analysis that—

8.10.1 Substantiates ice protection coverage in relation to chord length and span,

8.10.2 Substantiates the IPS power density, and

8.10.3 Considers the effect of inter-cycle ice accretions and potential for propeller efficiency degradation. Qualitative analysis of the design supported by similarity to prior designs with successful service histories in icing may be used to show compliance with this aspect.

8.11 **Airspeed Indication and Static Pressure System Ice Protection.**

8.11.1 Compliance with the minimum performance standard in Technical Standard Order (TSO) TSO-C16a, *Electrically Heated Pitot and Pitot-Static Tubes*, is not sufficient by itself to show compliance with § 25.1323. Section 25.1323 requires a heated pitot probe or an equivalent means of preventing malfunction due to icing conditions specified in Appendix C, certain Appendix O icing conditions, and in specific mixed phase icing and ice crystal conditions. It is unlikely that the icing conditions critical to the equipment will be encountered during flight tests. Consequently, certification programs should supplement the icing flight tests with icing tunnel test and/or tanker test data, as necessary. In-service experience during severe atmospheric conditions has shown that use of pitot probes qualified to the older standards has resulted in airspeed fluctuations and even loss of indicated airspeed. However, similarity to a previous pitot probe installation with positive in-service history may be a consideration when showing compliance. Section 25.1326 requires a system to advise the flightcrew when a pitot heating system is not operating. An acceptable indication system may consist of separate lights or a flightcrew alert indication on an electronic display for each pitot source. Additional guidance on an acceptable means of compliance with § 25.1326 is provided in AC 25-11B, *Electronic Flight Deck Displays*.

8.11.2 TSO-C16a references Society of Automotive Engineers (SAE) Aeronautical Standard AS8006, *Minimum Performance Standard for Pitot and Pitot-Static Tubes*, and supplements the icing requirements with specific part 25, Appendix C icing conditions and specific liquid water content tests from British Specification 2G 135, *Specification for Electrically-Heated Pitot and Pitot-Static Pressure Heads.* However, it does not contain tests for Appendix O icing conditions, mixed phase, or ice crystal conditions. The applicant is responsible for showing that the pitot heat is adequate for the Appendix C and applicable Appendix O icing conditions. If this proof of compliance is not obtained in flight tests, analysis or icing tunnel test data should be submitted.

8.11.3 Although Appendices C and O of part 25 only consider the liquid water content of icing conditions, recent cloud characterization research has indicated that approximately 40 percent of icing condition events consist of liquid water drops and ice crystals (mixed phase icing conditions). Also, glaciated atmospheric conditions, which consist solely of ice crystals, are encountered during airplane operations. The ice crystal environment may be more critical than liquid water for thermal systems because evaporating ice crystals requires more energy. Section 25.1323(i) requires a means to prevent malfunctions in the mixed phase and ice crystal requirements described in part 33, Appendix D. Appendix D of part 33 provides an environmental definition of conditions that may be encountered. These environmental conditions include parameters for total water content as a function of temperature, altitude, and horizontal extent. Altitude is a parameter identified in Appendix D of part 33 and must be considered when developing the test conditions and supporting analysis necessary to show compliance. In addition, ice crystal concentrations at an exterior mounted probe could be higher than the free stream conditions defined in Appendix D of part 33. Therefore, installation effects should be evaluated. A combination of CFD codes and icing tunnel testing would be an acceptable method of compliance. If not enough heat is provided to melt the ice crystals in mixed phase or ice crystal conditions, blocked pitot probes can result. Blocked pitot probes can prevent accurate airspeed indications. Icing tunnel tests with simulated mixed phase and glaciated icing combined with analysis is an acceptable way to show compliance with § 25.1323.

8.11.4 To ensure proper drainage, airspeed indication probes should be evaluated in the heavy rain conditions described in § 25.1323(i) as installed on the airplane. It is foreseeable that flight into freezing conditions could occur after encountering heavy ground level rain. If not enough heat is provided under these conditions, blocked pitot probes and inaccurate airspeed indications can result. Pitot probes should continue to operate after such an encounter.

8.12 Stall Warning System and Angle-of-Attack Ice Protection.

8.12.1 Compliance with the minimum performance standard for stall warning instruments in TSO-C54, *Stall Warning Instruments*, is not sufficient by itself to show compliance with § 25.1324. Section 25.1324 requires a heated angle-of-attack system sensor or equivalent means to prevent malfunction due to icing conditions specified in Appendix C, certain Appendix O icing conditions, and specific mixed phase icing and ice crystal conditions. AC 25-25A contains additional guidance on stall warning requirements.

8.12.2 With certain exceptions and additions, TSO-C54 requires compliance with performance specifications of SAE Aerospace Standard AS403A, *Stall Warning Instrument*. As in AS393B, *Airspeed Tubes Electrically Heated*, these requirements include a test to demonstrate deicing and anti-icing capability, but only temperature and airspeed are specified. The precipitation test conditions of SAE AS403A include moderate icing conditions for Type II instruments. "Moderate," however, is not defined. Although functioning of angle-of-attack sensors is evaluated in natural icing conditions during certification test programs, there is no requirement to flight test at the Appendix C or Appendix O icing limits because the low probability of finding those conditions imposes a burden. The applicant is responsible for showing that stall warning heat is adequate for the Appendix C and applicable Appendix O icing conditions. If proof of this is not obtained in flight tests, analysis or icing tunnel test data should be submitted.

8.12.3 Section 25.1324 also requires consideration of the mixed phase and glaciated icing conditions defined in part 33, Appendix D, for angle-of-attack sensors. Conventional trailing vane designs are such that ice crystals are not likely to be captured. A qualitative analysis based on the service history on trailing vane angle-of-attack sensors is an acceptable means of compliance.

8.12.4 In addition, § 25.1324 requires consideration of heavy rain conditions. To ensure proper drainage, angle-of-attack sensors should be evaluated in the heavy rain conditions as installed on the airplane. It is foreseeable that flight into freezing conditions could occur after encountering heavy ground level rain. Angle-of-attack sensors should continue to operate after such an encounter.

8.13 Runback Ice.

Water not evaporated by thermal IPSs and unfrozen water in near-freezing conditions (or in conditions when the freezing fraction is less than one) may run aft and form runback ice. This runback ice can then accumulate additional mass from direct impingement. The determination of runback ice is described in further detail in AC 20-73A. Runback ice should be considered when determining critical ice shapes. Simulated runback ice shapes may be used when evaluating effects of critical ice shapes. The applicant should consider potential hazards resulting from the shedding of runback ice.

9 SIMULATED ICE SHAPES AND ROUGHNESS.

AC 25-25A contains guidance on icing exposure during various phases of flight that should be considered when determining simulated ice shapes and surface roughness. AC 20-73A also contains additional guidance related to simulated ice shapes. The shape and surface roughness of the ice should be developed and substantiated with acceptable methods. Common practices include—

9.1 Use of computer codes for modeling drop impingement limits and ice shape predictions (see SAE ARP5903, Droplet Impingement and Ice Accretion Computer Codes),

9.2 Flight in measured natural icing conditions, 9.3 Icing wind tunnel tests (see SAE ARP5905, Calibration and Acceptance of Icing Wind Tunnels), and

9.4 Flight in a measured controlled simulated icing cloud (e.g., behind an icing tanker, see SAE ARP5904, Airborne Icing Tankers).

10 CRITICAL ICE SHAPES.

When developing critical ice shapes, the applicant should consider ice accretions that will form during all phases of flight and those that will occur before activation of the IPS. If applicable, runback, residual, and inter-cycle ice accretions should also be considered.

10.1 The applicant should assume that, during holding conditions, the airplane will remain in a rectangular “race track” pattern, with all turns being made within the 17.4 nautical mile icing cloud. Therefore, no horizontal extent correction should be used for this analysis.

10.2 The applicant should substantiate the drop diameter distribution (mean effective, median volume, spectra), liquid water content, and temperature that will cause formation of an ice shape critical to the airplane’s performance and handling qualities.

10.3 Ice roughness used should be based on icing tunnel, natural icing, or tanker testing.

10.4 See AC 20-73A for more information on critical ice shapes.

11 COMPLIANCE TESTS (FLIGHT/SIMULATION).

11.1 The following paragraphs address methods normally used to show compliance with §§ 25.1419 and 25.1420. These requirements state that the airplane must be able to operate safely in the continuous maximum and intermittent maximum icing conditions described in Appendix C and in the applicable icing conditions described in Appendix O. The airplane should be shown to comply with certification requirements when all IPS are installed and functioning. This can normally be accomplished by performing tests in those conditions found to be most critical to basic airplane aerodynamics, IPS design, and powerplant functions. All IPS equipment should perform its intended function throughout the entire operating envelope.

11.2 The primary purposes of flight testing are to—

11.2.1 Determine that the IPS is effective and performs its intended functions during flight as predicted by analysis or ground testing.

11.2.2 Evaluate any degradation in performance and flying qualities.

11.2.3 Show compliance with the performance and handling qualities requirements identified in § 25.21(g). Flight tests to show compliance with these requirements are addressed in

AC 25-25A. Flight testing also verifies the adequacy of flightcrew procedures as well as limitations for the use of the IPS in normal, abnormal, and emergency conditions.

11.2.4 Confirm that the powerplant installation as a whole (engine, inlet, anti-ice system, etc.) performs satisfactorily in icing conditions. If the auxiliary power unit performs essential functions, it should be evaluated for performance in icing conditions. In accordance with part 33, engine icing certification results should also be carefully reviewed before any part 25 engine or airframe icing flight tests to determine if there were any anomalous results requiring special airplane/engine operating procedures.

11.3 Both §§ 25.1419 and 25.1420 require two or more means of compliance for flight in icing approval. It is common to use a combination of methods in order to adequately represent the conditions and determine resulting degradation effects with sufficient confidence to show compliance.

11.3.1 Dry Air Ground Tests.

Depending on details of the IPS design, some preliminary ground tests of the equipment may be warranted to verify the basic function of each item. The applicant should collect quantitative data, as necessary, to verify the system designs. These data should include operating temperatures of thermal devices, deicing fluid flow rates, and operating pressures and rates of inflation of pneumatic components.

11.3.2 Dry Air Flight Tests with Ice Protection Equipment Operating.

The first flight tests conducted to evaluate the airplane with the IPS operating are usually dry air flight tests. The initial dry air tests are conducted to verify that the IPS does not affect flying qualities of the airplane in clear air, and to obtain a thermal profile of an operating thermal IPS.

11.3.3 Typical Dry Air Flight Test Practices for Commonly Used Ice Protection Systems.

Several commonly used IPSs and components are discussed below to illustrate typical dry air flight test practices. Other types of equipment should be evaluated as their specific design dictates.

11.3.3.1 Thermal Ice Protection Leading Edge Systems.

Dry air flight tests are conducted to verify the system design parameters and thermal performance analyses.

11.3.3.1.1 Normally, instruments are installed on system components to measure the anti-icing mass flow rate or energy input (for electrical systems), supply air temperature, and surface temperatures. The dry air test plan generally includes operating conditions such as the climb, holding, and descent phases of a normal flight profile. Since the presence of moisture can affect surface temperatures, tests should be conducted where no visible moisture is present.

11.3.3.1.2 Measurements of supply air mass flow rate, energy input, and air temperature allow determination of how much heat is available to the system. The adequacy of the IPS can then be demonstrated by comparing the measured data to the theoretical analysis for both Appendix C and either Appendix O for compliance with § 25.1420(a)(3) or the portion of Appendix O proposed for compliance with § 25.1420(a)(2). Surface temperatures measured in the dry air, for example, can be useful in extrapolating the maximum possible leading edge surface temperature in flight, the heat transfer characteristics of the system, and the thermal energy available for the IPS. Supply air temperatures or energy input may also be used to verify that the IPS materials were appropriately chosen for the thermal environment.

11.3.3.2 Pneumatic Leading Edge Boots.

Tests should demonstrate a rise and decrease in operating pressures, which results in the effective removal of ice. This pressure rise time, as well as the maximum operating pressure for each boot, should be evaluated throughout the altitude range defined in Appendices C and O. Boots should be operated in flight at the minimum envelope temperature (-22 °F) of Appendix C continuous maximum icing conditions and Appendix O. This is to demonstrate adequate performance throughout the entire flight envelope and to demonstrate that no damage occurs during inflation and deflation. The appropriate speed and temperature limitation (if any) on boot activation should be included in the AFM. Boot inflation should have no significant effect on airplane performance and handling qualities.

11.3.3.3 Electrically Heated Propeller Boots.

For compliance with provisions of §§ 25.901(c), 25.903(b), 25.929, and 25.1419(c):

11.3.3.3.1 When flight testing in dry air, surface temperature measurements should be made and monitored to confirm proper function. These measurements are useful for correlating analytically predicted dry air temperatures with actual temperatures, and as a general indicator that the system is functioning and that each deicer is heating. It is suggested that system current, brush block voltage (i.e., between each input brush and the ground brush), and system duty cycles be monitored to ensure that adequate power is applied to the deicers.

11.3.3.3.2 System operation should be checked throughout the full revolutions per minute and propeller cyclic pitch range expected during flight in icing. All significant vibrations should be investigated.

11.3.3.3.3 The applicant should consider the maximum temperatures a composite propeller blade may be subjected to when deicers are energized. It may be useful to monitor deicer bond-side temperatures. When performing this evaluation, the most critical conditions should be investigated (e.g., airplane on the ground or propellers not rotating) on a hot day with the system inadvertently energized.

11.3.3.4 Windshield Anti-Ice.

Section 25.773(b)(1)(ii) requires that the airplane have a means of maintaining a clear portion of windshield in the icing conditions defined in Appendix C and in certain Appendix O icing conditions. The applicant should conduct dry air flight tests to verify the thermal analysis. Measurements of both the inner and outer surface temperature of the protected windshield area may be needed to verify the thermal analysis. Thermal analysis should show that the windshield surface temperature is sufficient to maintain anti-icing capability without causing structural damage to the windshield. An evaluation of visibility, including distortion effects through the protected area, should be made for both day and night operations. In addition, the size and location of the protected area should be reviewed to confirm that it provides adequate visibility for the flightcrew, especially during the approach and landing phases of flight. Analysis of exposures to Appendix C and Appendix O conditions should consider holding operations consistent with the applicable “Holding Ice” definition contained in Part II of those appendices.

11.3.3.5 Bleed Air Systems.

Effects of bleed air extraction on engine and airplane performance, if any, should be examined and included in the AFM performance data. The surface heat distribution analysis should be verified for varying flight conditions including climb, cruise, hold, and descent. Temperature measurements may be necessary to verify the thermal analyses. In accordance with provisions of § 25.939(a), the maximum bleed air for ice protection should have no detrimental effect on engine operation throughout the engine’s power range.

11.3.4 Dry Air Flight Tests with Predicted Simulated Ice Shapes and Roughness.

The primary function of dry air flight tests with simulated ice shapes is to demonstrate the ability of the airplane to operate safely with an accumulation of critical ice shapes based on exposure to Appendix C icing conditions and applicable Appendix O icing conditions. The specific flight tests used to evaluate airplane performance and handling qualities are addressed in AC 25-25A. In addition, effects of ice accretion on locations forward of pitot-static sensors, angle-of-attack sensors, and static pressure ports should be assessed. For failure conditions of the IPS that are not extremely improbable, validation testing may be required to demonstrate that the effect on safety of flight (as measured by degradation in flight characteristics) is commensurate with the failure probability. Such validation testing may consist of flight tests, flight simulator tests, wind tunnel tests, or validated CFD analyses.

11.3.5 Icing Flight Tests.

Flight tests in measured natural icing and tests performed with artificial icing tools, such as icing tankers, are normally used to demonstrate that the IPS performs during flight as predicted by analysis or other testing. Such tests are also used to confirm analyses used in developing the various components, such as ice detectors, and ice shapes.

Section 25.1419 requires measured natural icing flight tests within the icing conditions of Appendix C. If necessary, measured natural icing flight tests should be accomplished in Appendix O conditions. The natural icing flight tests are accomplished to corroborate the general nature of the effects on airplane handling characteristics and performance determined with simulated ice shapes (see AC 25-25A), as well as to qualitatively assess the analytically predicted location and general physical characteristics of the ice accretions. If necessary, there should be a means to measure and record ice accumulations and impingement limits. These can be approximated by various means, such as a rod mounted on the airfoil and black paint on the airfoil to increase the contrast between the ice accretion and the airfoil.

11.3.5.1 Instrumentation.

The applicant should plan sufficient instrumentation to allow documentation of important airplane, system, and component parameters, as well as icing conditions encountered. The following parameters should be considered:

11.3.5.1.1 Altitude.

11.3.5.1.2 Airspeed.

11.3.5.1.3 Engine power level or speed.

11.3.5.1.4 Propeller speed and pitch, if applicable.

11.3.5.1.5 Temperatures that could be affected by ice protection equipment or ice accumulation or that are necessary for validation of analyses, such as the temperatures of—

- Static air,
- Engine components,
- Electrical generation equipment,
- Surfaces, and
- Structural components.

11.3.5.1.6 Liquid water content. This should be measured over the complete water drop size distribution.

11.3.5.1.7 Median volume drop diameter and drop diameter spectra. When measurement of the icing environment drop diameter is necessary, instrumentation used for measuring drop sizes should be appropriate for the Appendix C and Appendix O icing conditions. For airplanes to be certified to a portion or all of Appendix O, measuring and recording drop diameter spectra should be accomplished.

11.3.5.1.8 Microscopic measurement of drop impact craters on a gelatin oil or soot slide exposed to an icing cloud may be an impractical way of measuring a median volume drop diameter because of the splashing and bouncing characteristics of large drops. Also, gelatin oil or soot slides are impractical for recording the drop diameter spectra of Appendix O type clouds. MVDs and drop diameter distributions are more practically obtained with more sophisticated equipment, such as laser-based drop measuring and recording instruments, or their equivalent. Depending on the drop size measurement capability of the instruments used, more than one instrument may be required to measure the expected range of drop diameters. If testing is performed with a calibrated icing tanker, large drop instrumentation on the test airplane may not be necessary. Some icing conditions may contain mixed phase icing (liquid plus ice). The instrumentation should provide the ability to distinguish between liquid drops and ice crystals. Equipment should be calibrated and properly maintained to obtain quality data.

11.3.5.2 Artificial Icing.

11.3.5.2.1 Flight testing in artificial icing environments, such as behind icing tankers, is one way to predict capabilities of individual elements of the ice protection equipment and to determine local ice shapes. Since the ice plume has a limited cross-section, testing is usually limited to components, such as heated pitot tubes, antennas, air inlets including engine induction air inlets, empennage, airfoil sections, and windshields. Calibration and verification of the icing cloud produced by the tanker should be accomplished as necessary for meeting test objectives. SAE ARP5904 provides recommended practices for using tanker icing simulations.

11.3.5.2.2 Use of an icing tanker can provide high confidence in local icing effects. But obtaining small drop sizes may be difficult with some spray nozzles. As a result, these methods could produce larger ice build-ups and different ice shapes than those observed in natural Appendix C icing conditions. Icing tanker techniques can be used in a manner similar to icing tunnel testing with respect to ice shape development. The plume may be of sufficient size that it could be applied to sections of the airframe to examine any potential hinge moment or $C_{L_{MAX}}$ effects from ice accretions behind protected areas in Appendix C or Appendix O conditions. This method also has the advantage of being able to combine the effects of thermal systems (such as runback) with direct accretion to simulate resulting ice accumulations. Tanker simulation could also be used to estimate accretion areas for use in estimates of drag from extended accretion regions (such as ice accretions extending beyond a radome) during exposures to Appendix O conditions. Atmospheric effects such as humidity and drop residence time (time required to bring the drop to static temperature) should be considered in this type of testing.

11.3.5.3 Appendix C Natural Icing Flight Testing.

11.3.5.3.1 Section 25.1419(b) requires measured natural icing flight tests. Flight tests in measured natural icing conditions are intended to verify the ice protection analysis, to check for icing anomalies, and to demonstrate that the IPS and its components function as intended. AC 20-73A provides additional information useful for planning a natural icing flight test program. The airplane should be given sufficient exposure to icing conditions to allow extrapolation to the envelope critical conditions by analysis. Test data obtained during these exposures may be used to validate the analytical methods used and the results of any preceding artificial icing tests.

11.3.5.3.2 Past experience indicates that an airplane performing flight testing in natural intermittent maximum icing conditions may be exposed to lightning strikes, severe turbulence, and hail encounters that could extensively damage it. When design analyses show that the critical ice protection design points (i.e., heat loads, critical ice shapes, accumulation, accumulation rates, etc.) are adequate under these conditions, and sufficient ground or flight test data exist to verify the analysis, a flight test in intermittent maximum icing conditions may not be necessary.

11.3.5.3.3 Flight testing in natural icing conditions should also be used to verify AFM procedures for activation of the IPS, including recognition and delay times associated with IPS activation. Such testing should verify the analytically predicted location and general physical characteristics of the ice accretions. Critical ice accumulations should be observed, where possible, and sufficient data taken to allow correlation with dry air testing. Remotely located cameras either on the test airplane or on a chase airplane have been used to document ice accumulations on areas that cannot be seen from the test airplane's flight deck or cabin.

11.3.5.3.4 For an airplane with a thermal deicing system, the applicant should demonstrate the effectiveness of the deicing operation either in artificial icing conditions or during a natural icing flight test certification program. The tests usually encompass measurements of the surface temperature time history. This time history includes the time at which the system is activated, the time at which the surface reaches an effective temperature, and the time at which the majority of ice is shed from the leading edge. The data should be recorded in the flight test report.

11.3.5.3.5 The applicant should perform a test to determine if moisture can be trapped and prevent normal operation of deicing boots or surface mounted sensors if the moisture freezes during flight. To verify proper operation of the deicing boots and surface mounted sensors, the airplane should operate on the ground in moderate rain; take off and fly through moderate rain;

and climb and maintain an altitude above the freezing level. During this test, all IPS should be operated in accordance with the AFM procedures.

11.3.5.4 Appendix O Natural Icing Flight Testing.

Section 25.1420(a) requires airplanes with a certified maximum takeoff weight less than 60,000 pounds or equipped with reversible flight controls to operate safely in the supercooled large drop icing conditions defined in part 25, Appendix O.

11.3.5.4.1 Unless shown by other means, such as discussed in paragraph 11.3.5.4.2, flight testing in measured natural Appendix O icing conditions may be necessary to—

11.3.5.4.1.1 Verify the general physical characteristics and location of the simulated ice shapes used for dry air testing and, in particular, their effects on airplane handling characteristics,

11.3.5.4.1.2 Determine if ice accretes on areas where ice accretion was not predicted,

11.3.5.4.1.3 Verify adequate performance of ice detectors or visual cues,

11.3.5.4.1.4 Conduct performance and handling quality tests as outlined in § 25.21(g), and

11.3.5.4.1.5 Evaluate effects of ice accretion not normally evaluated with simulated ice shapes (on propeller, antennas, spinners, etc.) and evaluate operation of each critical airplane system or component after exposure to Appendix O conditions.

11.3.5.4.2 Flight testing in natural Appendix O icing conditions should not be necessary if similarity is shown to an airplane that has shown compliance with § 25.1419 and has a successful service history, or if—

11.3.5.4.2.1 The design analyses show that the critical ice protection design points (i.e., heat loads, critical ice shapes for performance and handling qualities, accumulation, accumulation rates, etc.) are adequate under Appendix O conditions and various airplane operational configurations, and

11.3.5.4.2.2 Except where Appendix E of this AC allows the use of one method to perform the analysis in paragraph 11.3.5.4.2.1 above, at least two different methods of predicting Appendix O ice accretions must be shown to provide similar results (ice accretion thickness, location). One method should be either an icing wind tunnel or icing tanker test.

Note: Icing tunnels and analysis with CFD codes are considered two different methods, but two different CFD codes are not.

11.3.5.4.2.3 Determination of the appropriate analyses and/or tests should include consideration of the need to evaluate more than one airplane component simultaneously.

11.3.5.4.2.4 One consideration for evaluating more than one component simultaneously could include evaluating airplane performance with propeller and airframe ice accretion or with asymmetric ice accretions from propeller wash.

11.3.5.4.2.5 Another consideration for evaluating more than one component simultaneously could include evaluating engine performance with inlet (including cooling ducts for engine accessories) ice accretions.

11.3.5.4.2.6 Another consideration for evaluating more than one component simultaneously could include evaluating the stall warning system and characteristics with ice accretion that affects air data used by stall protection systems.

11.3.5.4.3 The need for flight testing in natural Appendix O icing is reduced for airplanes limited to exiting from Appendix O conditions according to § 25.1420(a)(1) as a result of reduced exposure to such conditions.

11.3.5.4.4 Flight testing in natural Appendix O icing conditions should be accomplished for airplane derivatives whose ancestor airplanes have a service record that includes a pattern of accidents or incidents due to in-flight encounters with Appendix O conditions. For derivative airplanes whose ancestor airplane is free of accidents or incidents recorded in icing conditions, flight testing in natural Appendix O icing conditions should not be necessary.

11.3.6 Fluid Anti-Icing/Deicing Systems.

Flight testing should include evaluation of fluid flow paths to confirm that adequate and uniform fluid distribution over the protected surfaces is achieved. Fluid flow paths should be determined when the fluid is mixed with impinging water during system operation. A means of indicating fluid flow rates, fluid quantity remaining, etc., should be evaluated to determine that the indicators are plainly visible to the pilot and that the indications provided can be effectively read. A shutoff valve should be provided in systems using flammable fluids. Fluid anti-icing/deicing systems may be used to protect propellers and windshields as well as leading edges of airfoils. The fluid for windshield fluid anti-ice systems should be tested to demonstrate that it does not become opaque at low temperatures. The AFM should include information advising the flightcrew how long it will take to deplete the amount of fluid remaining in the reservoir.

11.3.7 Icing Wind Tunnel Tests.

11.3.7.1 Icing wind tunnels provide the ability to simulate natural icing conditions in a controlled environment. A variety of Appendix C icing conditions and

Appendix O freezing drizzle conditions can be simulated, depending on the tunnel. Icing wind tunnels have been used to evaluate ice shapes on unprotected areas and on or aft of protected areas, such as inter-cycle, residual, and runback ice. They have also been used to evaluate performance of IPSs, such as pneumatic and thermal systems. Scale models may be used in icing wind tunnels, with appropriate scaling corrections, if the scale testing on the component has been validated with full-scale testing or analysis. Hybrid models, with the full-scale leading edge extending beyond the impingement limits, may also be used. The applicant may use these models to estimate impingement limits, examine visual icing cues, and evaluate ice detection devices.

11.3.7.2 Surface temperature measurements are typically made for air-data instruments, such as pitot tubes, pitot-static pressure probes, and angle-of-attack probes, during icing wind tunnel tests to verify thermal analyses. The acceptability of the installed air-data instrument ice protection should be evaluated during natural or artificial icing tests.

11.3.8 Dry Air Wind Tunnel Tests.

Dry air wind tunnel testing using scaled models and ice shapes has been used to determine ice protection requirements. The scaling, including the effect of the roughness of the ice, should be substantiated using methods found acceptable to the authorities.

12 CERTIFICATION WITH § 25.1420.

Section 25.1420 requires that the airplane operate safely in the supercooled large drop icing conditions defined in part 25, Appendix O. For guidance on engineering tool capabilities, see Appendix E of this AC.

12.1 Certification with §§ 25.1420(a)(1) and 25.1420(a)(2).

As an alternative to the requirements of § 25.1420(a)(3), applicants have the option of complying with §§ 25.1420(a)(1) or (a)(2), which allows an airplane to be certified for a limited range of conditions, from certification to Appendix C only to certification to Appendix C and a portion of Appendix O. The icing conditions the airplane may be certified to fly through may be defined in terms of any parameters that define Appendix O conditions and could include phase of flight limits, such as takeoff or holding, in Appendix O or a portion of Appendix O. For example, an airplane may be certificated to take off in portions of Appendix O conditions, but not be certificated for holding in those same conditions. Substantiated means must be provided to inform flightcrews when the selected icing conditions boundary is exceeded. The applicant must show compliance with § 25.21(g) for exiting the restricted Appendix O icing conditions. Ice shapes to be tested are those representing the critical Appendix O icing conditions during recognition and subsequent exit from those icing conditions. Methods of defining the selected Appendix O icing conditions boundary should be considered early in the certification process, with concurrence from the appropriate ACO. See section 19 of this AC for specific guidance on AFM limitations and operating procedures.

Note: While this AC provides guidance on compliance with § 25.1420(a)(2), further advancements in engineering tools may be necessary before an applicant is able to substantiate compliance with this option. A 2009 review of engineering tool capabilities found that current technology does not support distinguishing between freezing drizzle and freezing rain in flight. Therefore, certification for a portion of Appendix O will be challenging and will require close coordination with certifying authorities. Consult Appendix E of this AC for additional details on engineering tool capabilities.

12.1.1 Selection of Appendix O Boundary.

The physics of ice accretion is complex. (See FAA Technical Report DOT/FAA/CT-88/8-1 for a detailed discussion on the icing physics process.) Some generalizations, however, can be made about the effects of supercooled water drop impingement and ice limits. The “modified inertia parameter” is a similarity parameter relating a water drop’s inertia to the drag from the airflow. The inertia of smaller drops tends to be dominated by the airflow effect, so their trajectories tend to follow the local streamlines of air. Sufficiently small drops, depending on the size of the drop and the airplane component they are approaching, may simply flow around the airframe. (A larger airplane component increases the flow disturbance ahead of the component, deflecting airflow and the trajectories of smaller drops.) On the other hand, the inertia of larger drops tends to dominate the airflow effect and so the trajectories tend toward straight lines. Thus, large drops are much less likely to miss the airframe. The modified inertia parameter depends very strongly on drop size. It depends strongly on airplane (or model) size and airplane (or tunnel) velocity, and it also depends on drop density and air viscosity and density. The modified inertia parameter assumes a spherical drop and does not reflect drop distortion, drop break-up, or drop splashing. Standard impingement parameters, such as impingement limits, overall impingement, and leading edge impingement, all increase as a function of the modified inertia parameter. Other influences affecting the object’s water collection efficiency, drop impingement, icing limits, ice shape, and runback ice include splashing of the large water drops and break-up of the large water drops when forces on the distorted drop exceed the surface tension required to hold the drop together. These latter influences become more evident for the larger drops defined in Appendix O. Drop size distributions and the related distribution of water mass are important considerations for water catch, impingement limits, and ice limits, as well as for runback ice. Consideration of these influences allows comparison of critical icing conditions that can be correlated to ice accretions in aft locations, such as behind protected areas.

12.1.2 The modified inertia parameter is commonly used in icing wind tunnel testing to compare high altitude flight conditions to the available low altitude test conditions. To simulate effects of high altitudes and true airspeeds on impingement, larger drops are used at the lower altitude test conditions. As an example, an IPS designed to protect against 50 µm drop impingement at 22,000 feet and 200 knots calibrated air speed (KCAS) (290 knots true air speed (KTAS)) would be equivalently protected against

76 µm drops at sea level and 200 KCAS (190 KTAS) because of an equivalent modified inertia parameter (assuming a 6-foot chord).

12.1.2.1 Based on these physical processes, it is difficult to select a boundary for Appendix O icing conditions based on drop size. Consideration of the drop inertia effects throughout the flight envelope will likely be required. While technology does not currently exist to discriminate icing conditions based on specific drop sizes (exclusive of inertia effects), methods may be developed in the future to certify airplanes for flight in icing in such a manner.

12.1.2.2 Alternative methods of defining a selected boundary for Appendix O icing conditions may be considered. For example, it may be possible to develop an exit cue so that unrestricted flight in Appendix O freezing drizzle is approved but exit is required from Appendix O freezing rain.

12.1.2.3 See Appendix C of this AC for an example of a plan for certificating to Appendix C only (§ 25.1420(a)(1)) based on drop size discrimination.

12.1.3 Means for Detecting Appendix O Boundaries.

Determining whether the selected boundary for Appendix O icing conditions has been exceeded can potentially be accomplished using visual cues, an ice detection system, or an aerodynamic performance monitor.

12.1.3.1 Ice detection systems and aerodynamic performance monitors are discussed in paragraph 15.5 of this AC. For compliance with § 25.1420(a)(1), it is acceptable to use an ice detection system that detects accretions behind the airplane's protected areas.

12.1.3.2 Substantiated visual cues can range from direct observation of ice accretions aft of the airplane's protected surfaces to observation of ice accretions on reference surfaces. Methods used to substantiate visual cues should be agreed on with the appropriate certification authorities. Responding to a cue should not require the flightcrew to judge the ice to be a specific thickness or size. Examples of potential visual cues are accretions forming—

- On side windshields,
- On sides of nacelles,
- On propeller spinners aft of a reference point,
- On radomes aft of a reference point, and/or
- Aft of protected surfaces.

12.1.3.2.1 Visual cues should be developed with the following considerations:

12.1.3.2.1.1 Visual cues should be within the flightcrew's primary field of view if possible. If outside the primary field of view, the cues should be visible from the design eye point and easily incorporated into the flightcrew's visual scan with a minimum of head movement while seated and performing their normal duties.

12.1.3.2.1.2 Visual cues should be visible during all modes of operation (day and night) without use of a handheld flashlight.

12.1.3.2.2 During the certification process, the applicant should verify the ability of the flightcrew to observe visual cues or reference surfaces. Visibility of the visual cues should be evaluated from the most adverse flightcrew seat locations in combination with the range of flightcrew heights, within the approved range of eye reference point locations, if available. A visual cue is required for both the left and right seats. If a single visual cue is used, it should be visible from each seat. Consideration should be given to the difficulty of observing clear ice. The adequacy of the detection method should be evaluated in all expected flight conditions. The applicant can carry out night evaluations with simulated accretions to assess visibility in and out of clouds.

12.1.3.2.3 Visual cues should be substantiated by tests and analysis, including tests in measured natural icing, or icing tanker tests, or potentially through icing wind tunnel tests. The applicant should consider the drop distributions of Appendix O when developing the cue, and the applicant should substantiate that these cues would be present in all the restricted Appendix O icing conditions. If a reference surface is used, the applicant should substantiate that it accumulates ice at the same time as or prior to ice accumulation on the critical surfaces.

12.1.3.2.4 AC 25-25A should be reviewed for guidance on the time flightcrews need to visually detect Appendix O icing conditions.

12.1.4 <u>Some Areas of Interest for Appendix O.</u>

The following are some areas of interest specific to supercooled large drop conditions:

12.1.4.1 Ice Shapes Aft of Protected Areas of Lifting Surfaces.

Appendix O icing conditions may result in a ridge of ice or ice roughness aft of the protected areas. On airplanes with reversible flight controls, a ridge of ice may cause uncommanded deflections of the control surfaces, which may result in an airplane upset. Airplanes may also incur reduced maximum lift and stall at lower angles of attack, independent of the flight control system. Appendix O ice build-ups can result in an airplane upset or stall if the stall protection system activation schedules are not adjusted.

12.1.4.2 Ice Shapes on Unprotected Areas of Lifting Surfaces.

Ice shapes resulting from Appendix O icing conditions can extend further aft on the airfoil than those from Appendix C icing conditions. When portions of the airfoil leading edge are unprotected, performance and handling qualities can be affected.

12.1.4.3 Ice Shapes on Unprotected Airframe Regions.

Areas of the airframe that do not accrete ice under Appendix C conditions should be examined for impingement and accretion in Appendix O conditions. The applicant should evaluate such issues as visibility through the windshield, locations of air-data sensors, and potential airflow disturbance (for example on the airplane nose) from Appendix O accretions that could influence performance of the air-data sensors.

12.1.4.4 Drag and Power Effects.

Airplanes may exhibit reduced performance in Appendix C conditions because ice accretions cause increased drag and reduced lift. Such impacts can be exacerbated in Appendix O conditions, since the accretions may extend further aft on protected areas, extend beyond protected areas, or occur in areas not typically protected (extended accretions on the fuselage and the lower wing surface, for example). Ice accretions may be rough and cause large local drag increases. Thrust effects of bleed penalties from system operations or degradation of thrust from powerplant losses (e.g., propeller icing) should be addressed. See AC 25-25A for more information about evaluating potential effects on airplane performance.

12.1.4.5 Engine Considerations.

Ice accumulation on the airframe and on air induction system components resulting from Appendix O icing conditions should be analyzed for potential ingestion of ice by the engine (relative to requirements of § 25.1093) and potential blockage effects. For § 25.1093 compliance, analysis may be used for the radome as a potential airframe ice source. Applicants may use qualitative analysis of the design supported by similarity to a previous design that has shown successful service history to have confidence that the historical methodology for certification represented by *Table 1—Minimum Ice Slab Dimensions Based on Engine Inlet Size* of § 33.77 is appropriate. Service history for designs similar to the ones under consideration should be part of the icing certification plan. In order to demonstrate compliance using similarity, the applicant should show successful service history of the previous design and establish confidence that the historical certification methodology is appropriate for the current certification.

12.1.4.6 Holding Ice Considerations.

Analysis of exposures to Appendix C and Appendix O conditions should consider holding operations consistent with the applicable “Holding Ice” definition contained in Part II of those appendices. Appendix O, Part II, contains different holding ice conditions depending on the level of certification requested in Appendix O conditions. For airplanes not certified to § 25.1420, the applicant should choose the holding ice conditions for which certification is sought. If the component will be certified for unrestricted operations in Appendix O, or a portion of Appendix O, then holding ice is defined in Appendix O, Part II, paragraph (c)(4). If the component will be certified for "detect and exit" operations, then the holding ice is defined in Appendix O, Part II, paragraph (b)(2).

12.2 Certification with § 25.1420(a)(3).

For compliance with § 25.1420(a)(3), if the AFM performance data reflects the most critical ice accretion (Appendix C and Appendix O) and no special normal or abnormal procedures are required in Appendix O conditions, then a means to indicate when the airplane has encountered Appendix O icing conditions is not required.

13 PNEUMATIC DEICER BOOTS.

Some existing AFMs specify a minimum ice accumulation thickness before activation of the deicer boot system. Such AFMs are associated with airplanes certified prior to § 25.1419, Amendment 25-129. This amendment added § 25.1419(e), (f), (g), and (h), which do not allow activation of airframe IPSs based on flightcrew visual observation of a specific thickness of ice. See section 15 of this AC for additional guidance on compliance with § 25.1419(e), (f), (g), and (h).

14 EMERGENCY AND ABNORMAL OPERATING CONDITIONS.

The applicant should conduct flight tests to demonstrate continued safe flight and landing following failures of the IPS using appropriate AFM abnormal and/or emergency operating procedures. Such demonstrations should be conducted with anticipated ice accumulations on normally protected surfaces. See part 25, Appendix C, and AC 25-25A for subpart B testing with failure ice shapes.

15 ICE AND ICING CONDITIONS DETECTION SYSTEMS.

Sections 25.1419(e), (f), (g), and (h) specify requirements for activation of the IPS. These requirements are only applicable to Appendix C icing conditions. Section 25.1420(c) requires compliance with § 25.1419(e), (f), (g), and (h) for the selected portion or all of Appendix O as applicable. Sections 25.1420(a)(1) and (a)(2), respectively, require a means to alert the flightcrew that they are in Appendix O icing conditions or have reached Appendix O icing conditions from which they must exit.

15.1 Compliance with § 25.1419(e)(1) and (e)(2).

These sections of the rule provide alternatives to operation of the IPS based on icing conditions defined in § 25.1419(e)(3). These alternatives require either a primary ice detection system or substantiated visual cues and an advisory ice detection system. Section 25.1419(e)(2) requires defined visual cues for recognition of the first sign of ice accretion on a specified surface combined with an advisory ice detection system that alerts the flightcrew to activate the airframe IPS. An acceptable means of compliance is described in the preamble of that rule, which states that the acceptability of visual cues combined with an advisory ice detection system is contingent on the following conditions:

15.1.1 The advisory ice detection system annunciates when icing conditions exist or when the substantiated visual cues are present.

15.1.2 The defined visual cues rely on the flightcrew's observation of the first sign of ice accretion on the airplane and do not depend on the pilot determining the thickness of the accretion.

15.1.3 The flightcrew activates the IPS when they observe ice accretion or when the ice detector annunciates ice, whichever occurs first.

15.1.3.1 Ice Detectors.

15.1.3.1.1 Primary Ice Detector. A primary ice detector must either alert the flightcrew to operate the IPS using AFM procedures or automatically activate the IPS before an unsafe accumulation of ice on the airframe, engine components, or engine air inlets occurs. The primary ice detection system must perform its intended function for the airplane configurations, phases of flight, and within icing envelopes of Appendix C and the applicable portion of Appendix O. Compliance for Appendix O conditions may be shown through qualitative analysis of the design, and supported by similarity to previous designs that have shown successful service history. Laboratory tests should demonstrate the ice detector's ability to function properly within all of the required icing conditions and airplane operating envelope. If similarity is not shown because of the lack of engineering tools for freezing rain, primary ice detectors used for compliance with § 25.1420(c) will require validation in natural large drop conditions to substantiate that the detectors function in all Appendix O conditions. If the ice detector cannot detect ice at low freezing fractions and ice accretes on the airplane in such icing conditions, the applicant should show that the airplane can be operated safely with the ice accretions. If safe operation cannot be substantiated, installation of an icing conditions detector may be required. Approval of the primary ice detector should include flight tests in measured natural icing conditions to verify analyses and laboratory test results, as well as to verify that the ice detector system performs its intended function. The primary automatic ice detection system should be designed to prevent frequent cycling up and down of engine thrust in intermittent icing conditions. However, small thrust changes will occur with the opening and closing of the engine bleed valves, resulting in a possible nuisance to the flightcrew.

15.1.3.1.2 Advisory Ice Detector. The advisory ice detector, in conjunction with another cue, such as visible ice accretion on referenced or monitored surfaces, should advise the flightcrew to initiate operation of the IPS using AFM procedures. An advisory system is not the only means used to determine if the IPS should be activated. When there is an advisory system installed on an airplane, the flightcrew has primary responsibility for determining when the IPS should be activated. Although the flightcrew has primary responsibility for determining when the IPS must be activated, if the airplane is certificated in accordance with § 25.1419(e)(2), the advisory ice detector should be part of the type design and not be provided as optional equipment. The advisory ice detector must also perform its intended function for the airplane configurations, for its phases of flight, and within the icing envelopes of Appendix C and the applicable portion of Appendix O. Analyses and tests similar to those performed for a primary ice detector should be performed for an advisory ice detector to understand its characteristics, limitations, and installation. If the advisory ice detector cannot detect ice at low freezing fractions and ice accretes on the airplane in such icing conditions that may go undetected by the flightcrew, installation of an icing conditions detector (i.e., one that detects both moisture *and* temperature), or additional substantiation with the resulting undetected ice accretions may be required.

15.1.3.1.3 Certification Plan. The applicant should present an icing certification plan, as suggested by section 7 of this AC, to the appropriate ACO. This plan should include the method selected for demonstrating the ice detector system's compliance with §§ 25.1301, 25.1309, 25.1419, and all other applicable sections. Appendix K of AC 20-73A provides guidance on certification of ice detector systems. That appendix provides guidance on ice detection response times as the freezing fraction drops below 1. That guidance is equally applicable to advisory and primary ice detection systems.

15.1.3.1.4 Performance of the Ice Detector System when Installed. The applicant should accomplish a drop impingement analysis and/or tests to ensure that the ice detector(s) are properly located. The applicant should show that under the various airplane operational configurations, phases of flight, airspeeds, and associated angles of attack, the ice detector is exposed to free-stream water drops. The ice detector should be located on the airframe surface where the sensor is adequately exposed to the icing environment. The applicant should conduct flow field and boundary-layer analyses of candidate installation positions to ensure that the ice detector sensor is not shielded from impinging Appendix C and Appendix O water drops. The ice detection system should be shown to operate in the range of conditions defined by Appendix C and the applicable portion of Appendix O. Sections 25.1419 and 25.1420 also require a combination of tests and analysis to demonstrate performance of the ice detector as installed on the airplane. This could include icing tunnel and icing tanker tests to evaluate ice detector performance. The applicant may use drop impingement analysis to determine that the ice detector functions properly over the drop range of Appendix C and the applicable portions of Appendix O when validated through natural or artificial icing tests (e.g., tanker, icing tunnel). The applicant should demonstrate that the airplane can be safely operated with the ice accretions formed up to the time the IPS becomes effective, following activation by the ice detector. The detector and its installation should minimize nuisance warnings.

15.1.3.1.5 Ice Detector System Safety Considerations. The applicant should consult AC 25.1309-1A for guidance on complying with § 25.1309. In accordance with the method of compliance in that AC, the applicant should accomplish a functional hazard assessment to determine the hazard level associated with failure of the ice detection system. The probability of encountering the icing conditions defined in Appendix C to part 25 should be considered to be 1. The unannunciated failure of a primary ice detection system is assumed to be a catastrophic failure condition, unless characteristics of the airplane in icing conditions without activation of the airframe IPS(s) are demonstrated to result in a less severe hazard category. If visual cues are the primary means of ice detection, the pilots retain responsibility to monitor and detect ice accretions when an advisory ice detection system is installed. However, the natural tendency of flightcrews to become accustomed to using the advisory ice detection system elevates the importance of the detector and increases the need to make flightcrews aware of an advisory ice detection system failure. Therefore, an undetected failure of the advisory ice should be considered as at least a major hazard unless substantiated as meriting a lower failure condition classification.

15.1.3.2 Visual Cues.

Visual cues can be either direct observation of ice accretions on the airplane's protected surfaces, or observation of ice accretions on reference surfaces. The first indications of accretions forming on any of the following are examples that could potentially be used as visual cues:

- The windshield wiper posts (bolt or blade).
- Propeller spinners.
- Radomes.
- The protected surfaces.

15.1.3.2.1 If accretions on protected surfaces cannot be observed, a reference system would be necessary if compliance with § 25.1419(e)(2) is desired. The applicant should consider providing a reference surface that can be periodically deiced to allow the flightcrew to determine if the airframe is continuing to accumulate ice. Without a means to deice the reference surface, compliance with § 25.1419(e)(2) would require operation of the

IPS as long are there is ice on the reference surface, even when additional ice is not accumulating. As the freezing fraction drops below 1, although some reference surfaces may not build up ice, ice may begin to accumulate on protected surfaces of the airplane. The applicant should show, for all the icing conditions defined in Appendix C and the applicable portions of Appendix O that the reference surface accumulates ice at the same time as or prior to ice accumulating on the protected surfaces.

15.1.3.2.2 Field of View. Visual cues should be developed with the following considerations.

15.1.3.2.2.1 Visual cues should be within the flightcrew's primary field of view, if possible. If cues are outside the primary field of view, they should be visible from the design eye point and easily incorporated into the flightcrew's vision scan with a minimum of head movement while seated and performing their normal duties.

15.1.3.2.2.2 Visual cues should be visible during all modes of operation (day, night, and in a cloud).

15.1.3.2.3 Verification. During the certification process, the applicant should verify the ability of the flightcrew to observe the visual cues. Visibility of the visual cues should be evaluated from the most adverse flightcrew seat locations in combination with the range of flightcrew heights, within the approved range of eye reference point locations, if available. A visual cue is required for both the left and right seats. If a single visual cue is used, it should be visible from each seat. The difficulty of observing clear ice should be considered, and the adequacy of the visual cue should be evaluated in all expected flight conditions. The applicant can carry out night evaluations with simulated accretions to assess visibility in and out of cloud. Visual cues should be substantiated by tests and analysis, including tests in measured natural icing.

15.2 Compliance with § 25.1419(e)(3).

This paragraph of § 25.1419 provides an alternative to the primary ice detection system and visual cues, plus the advisory ice detection system as defined in § 25.1419(e)(1) and (e)(2). This alternative requires operation of the IPS when the airplane is in conditions conducive to airframe icing during all phases of flight.

15.2.1 Temperature Cue.

The temperature cue used in combination with visible moisture should consider static temperature variations due to local pressure variations on the airframe. If the engine and airframe IPS are both activated based on visible moisture and temperature, a common conservative temperature for operation of both systems should be used. For example, if the engine IPS is activated at +5 °C static air temperature or less, the airframe IPS should be activated at the same temperature, even if it is substantiated that the airframe will not accrete ice above +2 °C static air temperature. This would ease the flightcrew workload and increase the probability of procedural compliance.

15.2.2 Either Total or Static Temperatures are Acceptable Temperature Cues.

If static temperature is used, a display of static air temperature should be provided to allow the flightcrew to easily determine when to activate the IPSs. As an alternative, a placard showing corrections for the available temperature, to the nearest degree Celsius, can be used, so the flightcrew can determine the static air temperature in the region of interest (that is, around 0 °C).

15.2.3 Airplane Flight Manual.

The Limitations section of the AFM should identify the specific static or total air temperature and visible moisture conditions that must be considered as conditions conducive to airframe icing and should specify that the IPS must be operated when these conditions are encountered.

15.3 Compliance with § 25.1419(f).

This paragraph of § 25.1419 states that requirements of § 25.1419(e)(1), § 25.1419(e)(2), or § 25.1419(e)(3) are applicable to all phases of flight unless it can be shown that the IPS need not be operated. To substantiate that the IPS need not be operated during certain phases of flight, the applicant should consider ice accretions that form during these phases, without the IPS operating, and establish that the airplane can safely operate in the continuous maximum and intermittent maximum icing conditions of Appendix C and the applicable portions of Appendix O.

15.4 Compliance with § 25.1419(g).

15.4.1 This paragraph of § 25.1419 requires that after the initial activation of the IPS—

15.4.1.1 The IPS must operate continuously,

15.4.1.2 The airplane must be equipped with a system that automatically cycles the IPS, or

15.4.1.3 An ice detection system must be provided to alert the flightcrew each time the IPS must be cycled.

15.4.2 The following are some examples of systems that automatically cycle the IPS so that the pilot does not have to manually cycle the IPS after initial activation:

15.4.2.1 A system that senses ice accretion on a detector and correlates it to ice accretion on a protected surface. This system then cycles the IPS at a predetermined rate.

15.4.2.2 A system that uses a timer to cycle the IPS. The applicant should substantiate that the airplane can safely operate with the ice accretions that form between the time one deicing cycle is completed and the time the next cycle is initiated. If more than one cycling time (a choice of 1- or 3-minute intervals for example) is provided, it should be substantiated that the flightcrew can determine which cycle time is appropriate.

15.4.2.3 A system that directly senses the ice thickness on a protected surface and cycles the IPS.

15.4.3 Some types of ice detection systems that alert the flightcrew each time the IPS must be cycled could operate in a manner similar to the automatic systems discussed above, except that the flightcrew would need to manually cycle the system. Flightcrew workload associated with such a system should be evaluated. Because of flightcrew workload and human factors considerations, a timed system without an ice sensing capability should not be used to meet this requirement. The ice shedding effectiveness of the selected means for cycling the IPS should be evaluated during testing in natural icing conditions. All inter-cycle and runback ice should be considered when showing compliance with § 25.21(g). See paragraph 15.1.1 of this AC for guidance on installed ice detector performance and safety considerations.

15.5 **Compliance with § 25.1420(a)(1) or (a)(2).**

These paragraphs of § 25.1420 require a means be provided to allow the flightcrew to detect when Appendix O conditions are encountered or when the selected portion of Appendix O conditions is exceeded. Means for determining when the selected portion of Appendix O icing conditions is exceeded may include visual means, ice detectors, or an airplane performance monitor. The substantiation of visual means is discussed in section 12 of this AC.

15.5.1 Ice Detectors.

An ice detector system installed for compliance with § 25.1420(a)(1) or (a)(2) is meant to determine when conditions have reached the boundary of the Appendix O icing conditions in which the airplane has been demonstrated to operate safely. For compliance with § 25.1420(a)(1), it is acceptable to use an ice detection system that detects accretions behind the airplane's protected areas. The applicant should accomplish a drop impingement analysis and/or tests to ensure that the ice detector is properly located to function during the airplane operational conditions and in Appendix O icing conditions. The applicant may use analysis to determine that the ice detector is located properly for functioning throughout the drop range of Appendix O conditions when validated with methods described in SAE ARP5903. The applicant should ensure that the system minimizes nuisance warnings when operating in icing conditions.

15.5.2 The low probability of finding conditions conducive to Appendix O ice accumulation may make natural icing flight tests a difficult way to demonstrate that the system functions in conditions exceeding Appendix C. The applicant may use airplane flight tests under simulated icing conditions (icing tanker). The applicant may also use icing wind tunnel tests of a representative airfoil section and an ice detector to demonstrate proper functioning of the system and to correlate signals provided by the detectors with the actual ice accretion on the surface.

15.5.3 Aerodynamic Performance Monitor.

A flightcrew-alerting system using pressure probes and signal processors could be developed for quantifying pressure fluctuations in the flow field from contamination over the wing surface. This technology does exist, but full development is necessary before incorporating it into the flightcrew-alerting system.

16 PERFORMING INTENDED FUNCTIONS IN ICING.

All systems and components of the basic airplane should continue to function as intended when operating in an icing environment. This includes the following:

16.1 Engines and Equipment.

Engines and equipment (such as generators and alternators operating under maximum ice protection load) should be monitored during icing tests for adequate cooling (§ 25.1041) and found acceptable for this operation (§§ 25.1093 and 25.1301).

16.2 Engine Alternate Induction Air Sources.

Engine alternate induction air sources should remain functional in an icing environment.

16.3 Fuel System Venting.

Fuel system venting should not be adversely affected by ice accumulation.

16.4 Landing Gear.

A retractable landing gear should operate as intended after an icing encounter.

16.5 Primary and Secondary Flight Control Surfaces.

Primary and secondary flight control surfaces should remain operational after exposure to icing conditions. The applicant should demonstrate either that aerodynamic balance surfaces are not subject to icing throughout the airplane's operating envelope (weight, center of gravity, and speed), or that no ice accumulation on these surfaces interferes with or limits actuation of the control for these surfaces, including retraction of flaps for a safe go-around from the landing configuration.

16.6 Ram Air Turbine.

The ram air turbine should remain operational. It does not need to be tested in natural icing conditions if tested in the icing wind tunnel.

17 ICE INSPECTION LIGHT(S).

Unless operations at night in icing conditions are prohibited by an operating limitation, § 25.1403 requires that a means be provided, during flight at night, to illuminate or otherwise determine ice formation on parts of the wings that are critical from the standpoint of ice accumulations.

17.1 If the flightcrew cannot see the wings, one acceptable means of compliance with this regulation would be to install an ice evidence probe in a position where the flightcrew can observe ice accumulation. The applicant should substantiate that formation of ice on this device precedes formation of ice on parts of the wings critical from the standpoint of ice accumulation, or occurs simultaneously with it. Consideration should be given to the need for illuminating the ice evidence probe.

17.2 Ice inspection lights should be evaluated both in and out of clouds during night flight to determine that the component of interest is adequately illuminated without excessive glare, reflections, or other distractions to the flightcrew. These tests may be accomplished both in and out of clouds during the airplane certification flight tests. Typically, airplane-mounted illumination has been used to comply with this regulation. If a hand-held flashlight is being considered for inspection illumination, the impact that use of a flashlight has on the associated flightcrew workload should be considered. Previously, use of a hand-held flashlight has not been acceptable because of the associated increase in flightcrew workload. The appropriate manual should identify the ice characteristics that the flightcrew is expected to observe, as well as the action that the flightcrew must perform if such ice is observed.

18 CAUTION INFORMATION.

Section 25.1419(c) requires that caution information be provided to alert the flightcrew when the IPS is not functioning normally. In this context, caution information is considered to be a general term referring to an alert rather than referring specifically to a caution level alert. Crew alerting should be provided for failure conditions of the IPS in accordance with §§ 25.1309(c) and 25.1322. It should be assumed that icing conditions exist during the failure event. In accordance with § 25.1419(c), the decision to provide an alert must not be based on the numerical probability of the failure event. However, the type of alert provided should be based on the failure effects and necessary crew action to be performed in response. Section 25.1420 describes requirements that are in addition to the requirements in § 25.1419 for certain airplanes and does not contain a requirement complementary to § 25.1419(c). Instead, it relies on compliance with § 25.1309(c) to ensure that adequate warning is provided to the flightcrew of unsafe system operating conditions. Warning information required by § 25.1309(c), to alert the flightcrew of unsafe system operating conditions, is applicable to design features installed to meet the additional requirements in § 25.1420 and must be provided in accordance with § 25.1322.

18.1 Sensor(s) used to identify a failure condition should be evaluated to ensure that they are properly located to obtain accurate data on the failure of the IPS.

18.2 The indication system should not be designed so that it could give the flightcrew a false indication that the system is functioning normally because of a lack of an alert. The applicant should submit data to substantiate that this could not happen. For example, if a pneumatic deicing system (boots) requires a specific minimum pressure and pressure rise rate to adequately shed ice, an alert should be provided if that minimum pressure and pressure rise rate are not attained. Without an alert, the flightcrew may erroneously believe that the boots are operating normally when, in fact, they might not be inflating with sufficient pressure or with a sufficient inflation rate to adequately shed ice. The applicant should also consider the need for an alert about ice forming in the pneumatic system that can result in low pneumatic boot pressures or an inadequate pressure rise rate.

19 AIRPLANE FLIGHT MANUAL.

The AFM should provide the pilot with the information needed to operate the IPS, including the following:

19.1 Operating Limitations Section.

19.1.1 Establishment of all systems limitations when operating in icing conditions. These limitations should address airframe, engine, and equipment IPSs, and other systems that may need to be specifically configured for operation in icing conditions. Appropriate icing conditions definitions may need to be provided to ensure proper operation of the related IPS.

19.1.2 Limitations on operating time for ice protection equipment, if these limitations are based on fluid anti-icing/deicing systems capacities and flow rates.

19.1.3 Airplane speed limitations (if any).

19.1.4 Environmental limitations for equipment operations as applicable (for example, minimum temperature or maximum altitude for boot operation). The AFM should include appropriate limitations to be observed in the event that icing conditions are encountered when the IPS cannot be activated.

19.1.5 Engine limitations (power or speed) required for proper operation of the IPS.

19.1.6 A list of required placards.

19.1.7 If compliance is based on § 25.1420(a)(1) or § 25.1420(a)(2), the Limitations section must include a requirement that the flightcrew exit all (Appendix O and C) icing conditions immediately on recognition that the Appendix O icing conditions exceed the certification boundary. The Limitations section must reflect the certification assumptions such as phase of flight, freezing drizzle, freezing rain, etc.

19.2 Operating Procedures Section.

19.2.1 Section 25.1585 requires that operating procedures be provided in the AFM for—

19.2.1.1 Normal procedures peculiar to the particular airplane type or model that are to be carried out in connection with routine operations,

19.2.1.2 Non-normal procedures for cases of malfunction and failure conditions involving use of special systems or the alternative use of regular systems, and

19.2.1.3 Emergency procedures for foreseeable but unusual situations in which immediate and precise action by the flightcrew may be expected to substantially reduce the risk of catastrophe.

19.2.2 The operating procedures required by § 25.1585 should include all preflight actions necessary to minimize the potential of en route emergencies associated with the IPS. System components should be described with sufficient clarity and depth that the pilot can understand their function. Unless flightcrew actions are accepted as normal airmanship, the appropriate procedures should be included in the FAA-approved AFM, AFM revision, or AFM supplement. These procedures should include proper pilot response to cockpit warnings, a means to identify system failures, and safe use of the system(s).

19.2.3 Procedures should be provided to optimize airplane operation while in icing conditions, including climb, holding, and approach configurations and speeds.

19.2.4 Emergency or abnormal procedures, including procedures to be followed when IPSs fail and/or warning or monitor alerts occur, should be provided.

19.2.5 For fluid anti-icing/deicing systems, information and method(s) for determining the remaining flight operation time should be provided.

19.2.6 For airplanes that cannot supply adequate electrical power for all systems at low engine speeds, load-shedding instructions should be provided to the pilot for approach and landing in icing conditions if pilot action is necessary.

19.2.7 For compliance with § 25.1420(a)(1) or § 25.1420(a)(2):

19.2.7.1 The method used to determine when icing conditions must be exited has to be provided, as well as appropriate failure indications and flightcrew procedures.

19.2.7.2 The operating procedures section should contain guidance for exiting the icing environment.

19.2.7.3 For an airplane certified to Appendix O for certain phases of flight, information defining the restricted phases should be provided. This information should include all airplane configurations associated with the restricted phases of flight, such as flap position, gear extension, or airspeed.

19.2.8 Section 25.1419(h) requires that procedures be established for operating the IPS, including activation and deactivation. Procedures for IPS deactivation must be consistent with the § 25.1419(e) requirements for activation of the IPS. The exact timing of deactivation should consider the type of IPS (e.g., deicing, anti-icing, or running wet) and all delays in deactivation necessary to ensure that residual ice is minimized. Pneumatic boots should be operated for three complete cycles following the absence of the cues used for activation. However, if the airplane's stall protection system reverts from an icing schedule to a non-icing schedule when the airframe IPS is deactivated, AFM procedures ought to state that the airframe IPS should not be deactivated until the flightcrew is certain that the critical wing surfaces are free of ice. For example:

19.2.8.1 If the airplane is certificated in accordance with § 25.1419(e)(2), pneumatic deicing boots may be deactivated following completion of three boot cycles after both the substantiated visual cues and the advisory ice detection system no longer indicate ice accretion.

19.2.8.2 If the airplane is certificated in accordance with § 25.1419(e)(3), pneumatic deicing boots may be deactivated following completion of three boot cycles after leaving icing conditions, even if residual ice is observed on the boots. The boots must be activated on reentry into icing conditions.

19.2.8.3 If the airplane's stall protection system reverts from an icing schedule to a non-icing schedule when the airframe IPS is deactivated, AFM procedures should state that the airframe IPS should not be deactivated until the flightcrew is certain that the critical wing surfaces are free of ice.

19.2.9 The following statement should be included in the operating procedures section of the AFM:

"Convective clouds above the freezing altitude that are vigorously increasing in size should be avoided because they may contain icing conditions exceeding those for which this airplane has been certified."

20 GUIDANCE FOR AMENDED TYPE CERTIFICATES AND SUPPLEMENTAL TYPE CERTIFICATES.

General guidance for amended TCs and STCs can be found in AC 21.101-1A, *Establishing the Certification Basis of Changed Aeronautical Products*. As stated in its "APPLICABILITY" section, the guidance in that AC applies to any STC or amended TC on an airplane for which the applicant seeks approval under provisions of §§ 25.1419 and 25.1420. Increases in gross weight, increases in engine power, and propeller changes could affect approval for flight in icing and these areas should be evaluated using AC 21.101-1A as the method of compliance. An applicant wishing to use an alternate means of compliance must consult the appropriate ACO. For additional guidance, see Appendix D of this AC.

21 INSTRUCTIONS FOR CONTINUED AIRWORTHINESS.

Instructions for Continued Airworthiness (ICA) are required in accordance with 14 CFR 21.50(b) and 25.1729. ICA should be prepared in accordance with part 25, Appendix H. At a minimum, the following should be addressed:

21.1 Basic description of the IPS operation, components, and installation.

21.2 Servicing information, such as fluid type and quantities.

21.3 Location of panels used for inspection, and/or instructions to access components.

21.4 Scheduling information for each applicable component including cleaning, inspecting, adjusting, testing, and lubricating.

21.5 Overhaul or replacement periods for components, if any.

21.6 Instructions for removing and replacing components.

21.7 Precautions, such as toxicity of freezing point depressant fluid or flammability of some cements.

21.8 Cleaning instructions, such as only soap and warm water for pneumatic deicing boots.

21.9 Limitations on the materials that can be applied, such as ice adhesion inhibitors, rubber preservatives, cosmetic coatings.

21.10 Recommendations on the frequency of ice adhesion inhibitors being used.

21.11 Special equipment or materials, such solvents, cements, edge filler, conductive edge sealer, or rollers for pneumatic boot installation.

Appendix A. Related Regulations and Documents

A.1 REGULATIONS.

Table A-1 identifies the sections of 14 CFR part 25 that are referenced in this AC. The full text of these regulations can be downloaded from the U.S. Government Printing Office e-CFR. A paper copy may be ordered from the Government Printing Office, Superintendent of Documents, Attn: New Orders, PO Box 371954, Pittsburgh, PA, 15250-7954.

Table A-1. Related Regulations

14 CFR	Title
§ 25.21	Proof of compliance
§ 25.103	Stall speed
§ 25.105	Takeoff
§ 25.107	Takeoff speeds
§ 25.111	Takeoff path
§ 25.119	Landing climb: All-engines-operating
§ 25.121	Climb: One-engine-inoperative
§ 25.123	En route flight paths
§ 25.125	Landing
§ 25.143	General (Controllability and Maneuverability)
§ 25.207	Stall warning
§ 25.237	Wind velocities
§ 25.251	Vibration and buffeting
§ 25.253	High-speed characteristics
§ 25.629	Aeroelastic stability requirements
§ 25.773	Pilot compartment view

14 CFR	Title
§ 25.875	Reinforcement near propellers
§ 25.929	Propeller deicing
§ 25.975	Fuel tank vents and carburetor vapor vents
§ 25.1091	Air induction
§ 25.1093	Induction system icing protection
25.1301	Function and installation (Equipment)
§ 25.1305	Powerplant instruments
§ 25.1309	Equipment, systems, and installations
§ 25.1316	Electrical and electronic system lightning protection
§ 25.1321	Arrangement and visibility (Instruments: Installation)
§ 25.1322	Flightcrew alerting
§ 25.1323	Airspeed indicating system
§ 25.1324	Angle of attack system
§ 25.1325	Static pressure systems
§ 25.1403	Wing icing detection lights
§ 25.1419	Ice protection
§ 25.1420	Supercooled large drop icing conditions
§ 25.1455	Draining of fluids subject to freezing
§ 25.1585	Operating procedures
Appendix C to part 25	
Paragraph K25.1.3(a) of Appendix K to part 25	Operations in icing conditions (Extended Operations (ETOPS)
Appendix O to part 25	Supercooled Large Drop Icing Conditions

A.2 ADVISORY CIRCULARS.

Table A-2 identifies the ACs that are related to the guidance in this AC. The table lists the latest version of each AC at the time of publication. If any AC is revised after publication of this AC, you should refer to the latest version for guidance. You can find the latest version at the FAA website.

Table A-2. Related Advisory Circulars

Number	Title	Date
AC 20-73A	Aircraft Ice Protection	August 16, 2006
AC 20-115C	Airborne Software Assurance	July 19, 2003
AC 20-117	Hazards Following Ground Deicing and Ground Operations in Conditions Conducive to Aircraft Icing	December 17, 1982
AC 20-147A	Turbojet, Turboprop, and Turbofan Engine Induction System Icing and Ice Ingestion	October 22, 2014
AC 21-16G	RTCA Document DO-160E versions D, E, F, and G, “Environmental Conditions and Test Procedures for Airborne Equipment”	June 22, 2011
AC 21-40A	Guide for Obtaining a Supplemental Type Certificate	September 27, 2007
AC 21.101-1A	Establishing the Certification Basis of Changed Aeronautical Products	September 3, 2010
AC 25-11B	Electronic Flight Displays	October 7, 2014
AC 25-22	Certification of Transport Airplane Mechanical Systems	March 14, 2000
AC 25-25A	Performance and Handling Characteristics in the Icing Conditions	October 27, 2014
AC 25.629-1B	Aeroelastic Stability Substantiation of Transport Category Airplanes	October 27, 2014
AC 25.1309-1A	System Design Analysis	June 21, 1988

A.3 OTHER FAA DOCUMENTS.

A.3.1 FAA Technical Report DOT/FAA/CT-88/8-1, *FAA Aircraft Icing Handbook*, issued March 1991, updated September 1993.

A.3.2 FAA Technical Report DOT/FAA/AR-09/10, *Data and Analysis for the Development of an Engineering Standard for Supercooled Large Drop Conditions*, dated March 2009.

A.3.3 FAA Policy No. ANE-2003-35-1-RO, *Policy for Propeller Ice Protection Equipment*, dated March 2, 2005.

A.4 INDUSTRY DOCUMENTS.

Table A-3 identifies the industry documents that are related to the guidance in this AC.

A.4.1 You can purchase the following RTCA, Inc. (formerly the Radio Technical Commission for Aeronautics) documents by mail from RTCA Inc., 1150 18th Street NW., Suite 910, Washington, DC 20036; by faxing the Document Order Form to (202) 833-9434; or from the RTCA website.

A.4.2 You can purchase the following SAE International (formerly Society of Automotive Engineers) documents by mail from SAE Customer Service, 400 Commonwealth Drive, Warrendale, PA, 15096; by faxing your order information to (724) 776-0790; or from the SAE website. Please note that the time of publication of this AC, the SAE documents have not been updated to reflect supercooled large drop analyses and testing but provide good reference material.

Table A-3. Related Industry Documents

Document	Title	Date
RTCA DO-178C	Software Considerations in Airborne Systems and Equipment Certification	December 13, 2011
RTCA DO-160G	Environmental Conditions and Test Procedures for Airborne Equipment	December 8, 2010
RTCA DO-254	Design Assurance Guidance for Airborne Electronic Hardware	April 19, 2000
SAE AIR1168/4	Ice, Rain, Fog, and Frost Protection	Issued July 1, 1989, Reaffirmed June 2004
SAE ARP5624	Aircraft Inflight Icing Terminology	Issued March 3, 2008, Reaffirmed April 2013
SAE ARP5903	Droplet Impingement and Ice Accretion Computer Codes	Issued October 16, 2003, Reaffirmed December 2009
SAE ARP5904	Airborne Icing Tankers	Issued October 21, 2002, Reaffirmed October 2012
SAE ARP5905	Calibration and Acceptance of Icing Wind Tunnels	Issued September 18, 2003, Reaffirmed December 2009
SAE AS393B	Airspeed Tubes Electrically Heated	Issued August 14, 2002, Reaffirmed February 2008
SAE AS403A	Stall Warning Instrument	Issued July 15, 1958, Reaffirmed February 2008
SAE AS5498 (EUROCAE ED-103)	Minimum Operational Performance Specification for Inflight Icing Detection Systems	Issued October 1, 2001, Reaffirmed December 2009
SAE AS8006	Minimum Performance Standard for Pitot and Pitot-Static Tubes	Issued April 1, 1988, Reaffirmed May 1993

Appendix B. History of Icing Certification Rules

B.1 CIVIL AIR REGULATIONS.

B.1.1 Before 1953, airplanes were certificated under part 04 of the civil air regulations (CARs). Section 04.5814 required that if deicer boots were installed on an airplane, positive means must be provided for deflation of all wing boots. There were no other references to an airplane ice protection system (IPS) in Part 04.

B.1.2 Part 4b of the CAR was codified on December 31, 1953. The requirement for positive means of deflating deicer boots was incorporated, without change, into § 4b.640. Section 4b.640 stated that, “When an ice protection system is installed, it shall be of an approved type. If pneumatic boots are used, at least two independent sources of power and a positive means for the deflation of the boots shall be provided.” Section 4b.351(b)(ii) provided requirements for pilot compartment vision in icing conditions. Section 4b.406 provided propeller-deicing requirements. Section 4b.461 gave induction system deicing and anti-icing requirements. Section 4b.612(a)(5) required that the airspeed indicating system be provided with a heated pitot tube or equivalent means of preventing malfunctioning due to icing.

B.1.3 Amendment 4b-2, effective August 25, 1955, introduced icing envelopes similar to those in the current Appendix C to part 25. The graphs added by Amendment 4b-2[1] were identical in substance and format to those describing the current Appendix C icing envelopes with a few exceptions. Those envelopes were defined by descriptions of the liquid water content (LWC), the mean effective diameter of drops, the temperature, and the horizontal and vertical extent of the supercooled icing cloud environment. In the figures introduced by Amendment 4b-2, the units of distances shown on the graphs were expressed in statute miles instead of nautical miles. The LWC in the Amendment 4b-2 figures and the current Appendix C envelopes is identical, however, if the correction for the difference between nautical and statute miles is made. There are two significant differences between the Amendment 4b-2 icing envelopes and those described in the current Appendix C.

B.1.3.1 The minimum mean effective diameter in the intermittent maximum conditions was 20 µm. The current diameter is 15 µm.

B.1.3.2 The minimum cloud horizontal extent in the chart titled *Intermittent Maximum Atmospheric Icing Conditions Variation of LWC Factor with Cloud Horizontal Extent* was 1.5 statute miles. The current horizontal extent is 2.6 nautical miles (3.0 statute miles).

[1] 4b-24a, 4b-24b, 4b-24c, 4b-25a, 4b-25b, and 4b-25c

B.1.4 Amendment 4b-6, effective August 12, 1957, revised the icing envelopes to those that exist in the current requirements. Amendment 4b-6 revised § 4b.461, *Induction system deicing and anti-icing provisions*. The preamble to that amendment states:

"There are included herein changes which extend the currently effective provisions governing intermittent maximum icing conditions so as to cover conditions which might be critical insofar as the turbine engine induction system is concerned. In this regard, the data are being extended in accordance with NACA Technical Note 2738 and involve a revision of figure 4b-25a to cover drop diameters as small as 15 μm and a revision of figure 4b-25c to cover distances down to 3.0 mile. The icing conditions prescribed in the currently effective regulations are applicable in the main to the airframe. The changes being made in section 4b.461 require the turbine powerplant to be subjected to the same icing conditions and require that the induction system be protected to prevent serious engine power loss. A similar requirement is incorporated with respect to certification of turbine engines by an amendment to Part 13 which is being made concurrently with this amendment."

B.2 **PART 25**.

B.2.1 Part 4b of the CAR was codified into 14 CFR part 25, effective February 1, 1965. The recodification, with minor editorial changes, resulted in the following:

B.2.1.1 The content of § 4b.640, *Ice protection*, became § 25.1419.

B.2.1.2 Section 4b.406, *Propeller deicing provisions*, became § 25.929.

B.2.1.3 Section 4b.612(a)(5), *Airspeed indicating systems*, became § 25.1323(e).

B.2.1.4 Section 4b.351(b)(1)(ii), *Pilot compartment view*, became § 25.773(b)(1)(ii).

B.2.1.5 The § 4b.351 reference to the most severe icing conditions for which approval of the airplane is desired was changed to reference the icing conditions specified in § 25.1419.

B.2.1.6 Section 4b.461, *Induction system deicing and anti-icing provisions*, became § 25.1093.

B.2.2 Amendment 25-5, effective July 29, 1965, revised § 25.1325(b) to require that the correlation between air pressure in the static pressure system and true ambient atmospheric static pressure is not changed when the airplane is exposed to the continuous and intermittent maximum icing conditions defined in Appendix C.

B.2.3 Amendment 25-11, effective June 4, 1967, revised § 25.1585 to require that the airplane flight manual include information on use of ice protection equipment.

B.2.4 Amendment 25-23, effective May 8, 1970, revised § 25.1419 to require that the effectiveness of the IPS and its components be shown by flight tests of the airplane or its components in measured natural atmospheric icing conditions. Before this amendment, flight tests in natural icing conditions were considered one means of compliance but were not mandatory. Amendment 25-23 also revised § 25.1309 to include additional requirements for certifying equipment, systems, and installations. The regulation was revised to require a comprehensive systematic failure analysis, supported by appropriate test, to ensure that, as the hazard of a failure increases, the probability of its occurrence decreases.

B.2.5 Amendment 25-38, effective February 1, 1977, added § 25.1403. That rule requires means for illuminating or otherwise determining the formation of ice on parts of the wings for which ice accumulation is critical. This requirement does not apply if operating limitations prohibit operations at night in icing conditions.

B.2.6 Amendment 25-43, effective April 12, 1978, added § 25.1326 to require installation of a pitot heat indication system on airplanes equipped with flight instrument pitot heating systems.

B.2.7 Amendment 25-46, effective December 1, 1978, added § 25.1416 to require specific standards for pneumatic deicer boots.

B.2.8 Amendment 25-72, effective July 20, 1990, transferred the contents of § 25.1416 to § 25.1419 for clarification and editorial improvement. In addition, the content of § 25.1416(c) was revised. This rule required a means to indicate to the flightcrew that the pneumatic deicing boot system is receiving adequate pressure and is functioning normally. It was revised to allow use of the "dark cockpit" concept—a warning when failure occurs rather than continual pilot monitoring of a healthy system.

B.2.9 Amendment 25-121, effective October 9, 2007, revised the following rules, which provide performance and handling qualities requirements for safe operation in Appendix C icing conditions:

- § 25.21.
- § 25.103.
- § 25.105.
- § 25.107.
- § 25.111.
- § 25.119.
- § 25.121.
- § 25.123.
- § 25.125.
- § 25.143.
- § 25.207.
- § 25.237.
- § 25.253.

B.2.10 In addition, Amendment 25-121 revised § 25.1419 to require compliance with § 25.1419 if certification for flight in icing is desired. Prior to that revision, compliance with § 25.1419 was only required if the airplane had ice protection provisions. Appendix C was revised to identify airframe ice accretion that must be considered for showing compliance with subpart B. Editorial revisions were made to §§ 25.773 and 25.941 to retain consistency with the changed § 25.1419 and to revise references to changed paragraphs.

B.2.11 Amendment 25-129, effective September 2, 2009, added § 25.1419(e), (f), (g), and (h) to provide requirements for determining when to operate IPS to ensure safe operation in Appendix C icing conditions.

B.2.12 Amendment 25-140, effective January 5, 2015, introduced Appendix O and §§ 25.1324 and 25.1420, and revised the following rules:

- § 25.21.
- § 25.105.
- § 25.111.
- § 25.119.
- § 25.121.
- § 25.123.
- § 25.125.
- § 25.143.
- § 25.207.
- § 25.237.
- § 25.253.
- § 25.773.
- § 25.903.
- § 25.929.
- § 25.1093.
- § 25.1323.
- § 25.1324.
- § 25.1325.
- § 25.1521.
- § 25.1533.
- Appendix C to part 25.

B.2.13 Amendment 25-140 expanded the certification icing environment to include freezing rain and freezing drizzle. The amendment specified airplane performance and handling qualities requirements for operating in these conditions. The amendment expanded the engine installation certification and some airplane component certification regulations to include ice crystal and mixed phase icing conditions. The amendment added a new icing regulation for angle-of-attack systems.

Appendix C. Example of Certification to 25.1420(a)(1) Using Visual Cues

The following is a hypothetical example of a certification program using the icing conditions of part 25, Appendix C, as the boundary for flight in icing. This example offers guidance on developing substantiated visual cues to identify the boundary so the flightcrew will know when that boundary has been exceeded and Appendix O conditions have been encountered so the flightcrew can exit icing conditions safely.

C.1 HYPOTHETICAL AIRPLANE.

C.1.1 The airplane is a transport category, turbofan airplane. It is a derivative of an existing type design that has already been type certificated for flight in icing, including compliance with § 25.1419 (Appendix C). The changes in the derivative airplane did not alter the original § 25.1419 compliance. The derivative airplane design is characterized by the following:

- The cruise altitude is above the Appendix C envelope.
- The wing design does not include leading edge devices.
- The airplane has ice protection over the full span of the wing and tailplane.
- The airplane has reversible flight controls on the roll and pitch axes.

C.1.2 AC 25-25A contains guidance on compliance with part 25, subpart B requirements. AC 20-147A, *Turbojet, Turboprop, and Turbofan Engine Induction System Icing and Ice Ingestion*, contains guidance for engine and engine installations. All applicable certification requirements must be met. However, for this example, only some aspects will be discussed.

C.2 IMPINGEMENT AFT OF THE PROTECTED AREAS OF LIFTING SURFACES.

The airplane has ice protection over the full span of the wing and horizontal stabilizer, with minimal unprotected areas. Since this is a derivative airplane, the system has already been evaluated and certificated for Appendix C conditions. This airplane does have reversible flight controls on the roll and pitch axis. An assessment of hinge moment and lift reduction effects is required. See AC 25-25A for detailed guidance on performance and handling qualities.

C.3 IMPINGEMENT AFT OF THE ENGINE INLET PROTECTED SURFACES.

The applicant should evaluate ice accumulation aft of the engine inlet protected surfaces for the possibility of ice ingestion by the engine. For this example, the cumulative mass of this ice is less than that used for demonstrating compliance with § 33.77. Therefore, this airplane will be found compliant with § 25.1093 based on this known ingestion standard. See AC 20-147A for further information on engine and engine installation certification.

C.4 ICE SHAPES ON UNPROTECTED AREAS OF LIFTING SURFACES.

The airplane is designed with full span ice protection on the wing and horizontal stabilizer. The unprotected areas (wing tip, stabilizer tip) are a small percentage of the effective airfoil areas. Aerodynamic effects of Appendix O accretions on the minimal exposure areas are unlikely to be critical, but should be investigated. See AC 25-25A for details on performance and handling qualities guidance.

C.5 ICE SHAPES ON UNPROTECTED AIRFRAME REGIONS.

The applicant should examine other areas of the airframe that do not accrete ice under Appendix C conditions because of the increased impingement limits and potential additional runback in Appendix O conditions. Issues such as windshield visibility, static port location, and potential airflow disturbance from Appendix O accretions that could influence sensors (total air temperature, pitot, and angle of attack) should be examined. A CFD analysis (icing impingement analysis) combined with a satisfactory field service history on derivative models may be sufficient to alleviate any potential concerns.

C.6 AIR DATA SENSORS.

The applicant should examine ice protection on air-data sensors to ensure adequate protection from exposure to Appendix O icing conditions.

C.7 DESIGN SUBSTANTIATION.

A review of the impingement analysis and runback ice data versus the protected area for the wing and horizontal stabilizer indicates that the wing is the critical surface for formation of a potential ridge behind the protected areas in front of the ailerons. The horizontal stabilizer has farther aft protection limits and has sufficient margin for contamination aft of the protected areas. Again, it is assumed that the horizontal stabilizer would be addressed, but that will not be presented in this example.

C.8 DETERMINATION OF EXIT CUES.

C.8.1 Although this airplane will be certified only for flight in Appendix C conditions, its operating envelope could result in exposing the airplane to any of the Appendix O icing conditions. Climbs and descents should be examined, but because of the transient nature of these encounters, they may not produce the critical accretions for Appendix O.

C.8.2 The recommended procedure for holding in icing conditions should be considered (e.g., whether flaps or landing gear should be extended). AFM-recommended procedures would include this operating information. The case to be evaluated will consider the flaps up, gear up configuration. Since ice accretions aft of the protected areas on the upper wing surface are the primary concern in this example, operational conditions are analyzed to determine the critical flight conditions for such accretions. The following conditions are determined to be critical:

C.8.2.1 Highest holding altitude within the conditions of Appendix O that maximizes watercatch (typically a function of ram air effects (effects of air exerting pressure) and liquid water content at defined static temperatures).

C.8.2.2 Highest true airspeed expected during holding conditions (typically high weight hold speed, which produces maximum water catch aft of protected areas upper surface.)

Note: Other operating conditions should be considered as required to determine the critical conditions.

C.8.3 Through a combination of impingement analysis, analytical ice shape prediction, and icing wind-tunnel testing, the applicant has determined that there is potential for an ice ridge to begin accumulating on the upper wing surface under these operating conditions when there is significant water content in drop sizes above a specific drop size and liquid water content. This specific drop size and liquid water content will be proposed as a condition for determining when icing conditions must be exited, and a visual exit cue will have to be set (see following paragraph). Note that such a drop size criterion is not a fixed boundary. At a lower altitude, and at a similar equivalent airspeed (similar angle of attack), slightly larger drop sizes are required to produce a similar accretion of ice behind the protected area. But this combination of drop size, liquid water content, and inertia in relation to the airplane is sufficient to potentially produce accumulations behind the protected areas. See the discussion on the modified inertia parameter in paragraph 12.1.1 of this AC and FAA Technical Report DOT/FAA/CT-88/8-1, *Aircraft Icing Handbook*, Chapter I, section 2 and Chapter IV, section 2.2.2.

C.9 DETERMINATION OF VISUAL EXIT CUE.

The target boundary will be icing conditions that exceed the specific drop size and liquid water content determined in the preceding paragraph (for high altitude, high speed hold). The target criterion for a visual exit cue is a surface on the airplane readily visible to the flightcrew that will indicate water collection in such drop sizes. A computational fluid dynamics analysis of the cockpit/fuselage area has determined that there are perceptible changes in impingement limits with increasing drop sizes along the side windows. The desired visual cue uses a specific portion of the windshield as a reference surface that can be correlated to ice accumulation on the wing. Preliminary impingement analysis indicates that this is feasible because as drop sizes increase, there is significant movement of the aft impingement limits on the windshield when the specific flight conditions of interest are considered. Based on this analysis, a specific location on the airplane side window is proposed as the place to assess a visible cue to determine when the Appendix O conditions that require exiting icing conditions have been encountered.

C.10 DEFINITION OF CRITICAL ICE ACCRETION.

C.10.1 The applicant proposes that the exit cue be based on the first sign of accretion. It has been determined that an accretion of approximately 1/16-inch is required on the reference surface in order for the flightcrew to detect it. This reference-surface accretion is then correlated to the specific ice accretion on the monitored surface (behind the leading edge). The applicant should consider the ice accretion corresponding to the first indication on the reference surface and factor in recognition time and time to initiate escape as described in AC 25-25A, appendix A. This correlation is based on a combination of analysis and icing wind tunnel testing.

C.10.2 At the specific critical operating condition, the time it takes to observe the visual cue results in accretion of a 1/8-inch ice ridge behind the protected area. The difference in ice thickness between the ice on the reference surface and that on the wing is due to differences in the local collection efficiencies between the side window and the area aft of the leading edge protected surface. Consideration of additional accretion during the exit from the icing conditions is required to determine the full ice shape to be evaluated for aerodynamic degradation effects.

C.11 EVALUATION OF CRITICAL ICE ACCRETIONS.

Wind tunnel testing of this critical accretion has determined that there are no hinge moment situations that result in changes in roll forces. However, there is a potential increase in stall speed that must be addressed in the stall warning system. Dry air flight testing is performed using simulated ice shapes. This flight testing is performed in a manner in which the ice shapes are gradually built up with limited spanwise exposure to evaluate the effects with minimal safety risk. The stall warning margins are evaluated. This evaluation results in a modification of the stall warning system to ensure that adequate stall margin exists both for the period before detection and during the exit from all icing conditions. See AC 25-25A for details on part 25, subpart B compliance.

C.12 VALIDATION OF THE VISUAL CUE.

C.12.1 The applicant will evaluate and validate use of the visual cue by flight testing with an icing tanker. The tanker is equipped to provide a specific median volume diameter icing condition with an associated drop distribution. Since the tanker cannot simulate the full array of Appendix O icing conditions, validation of specific conditions will be made. A fixed nozzle simulating the specific exit cue drop size will be used.

C.12.2 Icing tanker testing indicates that the side window begins to accumulate ice in the specific circumstances considered, which validates the analysis. At slower speeds, the drops do not have sufficient inertia to reach the side windows. This validates the fact that the visual cue is not overly sensitive and will not result in false indications. Tanker testing also shows good correlation with the predicted ice shapes, thus validating the expectation of a specific ice shape forming behind the protected areas. This location is adequately illuminated by existing cockpit lighting without glare or reflection, and is readily observable by flightcrew members.

C.13 **EXITING FROM RESTRICTED APPENDIX O ICING CONDITIONS**.

Flight tests are performed in accordance with § 25.21(g)(2) and (4) to show that the airplane can safely exit Appendix O icing conditions. See AC 25-25A for details on performance and handling qualities guidance.

Appendix D. Guidance for Amended Type Certificates and Supplemental Type Certificates

The guidance in this AC applies to any supplemental type certificate (STC) or amended type certificate (TC) on an airplane for which the applicant seeks approval under provisions of §§ 25.1419 and 25.1420. Increases in gross weight, increases in engine power, external modifications, and propeller changes could affect approval in icing and these areas should be evaluated using this AC as the method of compliance. An applicant wishing to use an alternate means of compliance should consult the appropriate FAA aircraft certification office.

D.1 EXAMPLES OF MODIFICATIONS FOR WHICH COMPLIANCE WITH ICING REGULATIONS SHOULD BE REVIEWED.

The following list is only an example and is not meant to be all inclusive:

- Engine changes.
- Propeller changes.
- Engine inlet or accessory inlet changes.
- Antennae installations or other external modifications.
- Gross weight increase.
- Center of gravity envelope increase.
- Flight envelope increase.
- Turboprop conversion.
- Modifications to lifting surfaces.
- Installation of vortex generators.
- Modifications to ice protections systems.

D.2 ENGINE CHANGES.

In addition to the guidance on similarity analysis provided in paragraph 8.7 of this AC, the applicant should address effects of increased engine power or thrust on airplane handling qualities in icing conditions, as well as on compliance with engine induction icing regulations, § 25.1093. AC 20-147A contains additional information on engine and engine installation certification.

D.2.1 Effects of Increased Engine Power or Thrust.

D.2.1.1 Stability and Control.

If increased engine power or thrust has potential for affecting airplane handling qualities in icing conditions, the applicant should conduct flight tests with ice accretions as described in AC 25-25A.

D.2.1.2 <u>Ice-Contaminated Tailplane Stall.</u>

An ice-contaminated tailplane stall (ICTS) should be addressed. See AC 25-25A for compliance materials on tailplane stall.

D.2.2 Engine Induction Icing.

D.2.2.1 <u>Similarity.</u>

D.2.2.1.1 If similarity to a previous design is used as a method of compliance, such documentation should be supplemented with analysis or testing, or both. In some cases, an analysis substantiating similarity, along with an installation survey conducted by the engine manufacturer, may be sufficient. The analysis should include the following:

- Heat requirements for the inlet lip ice protection, if installed.
- Location of the lip deicer thermostat, if installed.
- Inlet material to which the deicer is attached (heat sink may be different).
- Inlet geometry.
- Engine ignition system.
- Engine sensors.

D.2.2.1.2 Any differences that cannot be addressed by analysis should be addressed by flight testing. The data to be used for similarity, including data from a past certification on which the similarity analysis is based, must be available to the applicant and must be provided to the FAA upon request.

D.2.2.2 <u>Falling/Blowing Snow and Ground Ice Fog for Turbine Engines.</u>

If similarity to a previously certified airplane will be used as a method of compliance, the certification plan should state to which attributes of the ancestor airplane similarity will be shown. This is important because similarity may be based on a certified installation that does not have falling/blowing snow or ground ice fog in its certification basis. Service experience by itself cannot be used to show compliance. For turboprop installations, compliance is normally shown by testing. With regard to falling and blowing snow, inlets such as the oil cooler, as well as the induction system, are of concern. The certification plan should identify how compliance with these sections will be shown.

D.2.2.3 <u>Ice Shedding.</u>

Data showing engine compliance with § 33.77 should be compared between the currently installed engine and the proposed engine. If the ice slab used to show compliance is smaller for the proposed engine, ice shedding from the airframe should be re-addressed. Engine inlet lip ice shedding should be addressed. The applicant should compare the amount of ice mass that could be shed by the proposed installation to the amount that could be shed by a similar, approved installation. Alternatively, the amount of ice that could be shed should be compared to part 33 engine compliance data.

D.2.2.4 Ice Protection System Operation.

D.2.2.4.1 The applicant should compare the proposed engine to the existing, certified engine for—

- Bleed air mass flows,
- Pressures, and
- Temperatures.

D.2.2.4.2 If there is a reduction in any of these, the effectiveness of the IPS should be substantiated.

D.3 PROPELLER CHANGES.

D.3.1 Section 25.929 requires a means to prevent or remove hazardous ice accumulation on propellers or accessories where ice accumulation would jeopardize engine performance. The typical analysis report from the deicing boot manufacturer is not sufficient by itself to show compliance with § 25.929. The typical report calculates inter-cycle ice thicknesses for various flight and icing conditions, but does not calculate the effect on propeller efficiency, which must be done to show no appreciable loss of thrust. For STCs, it would be acceptable to show that inter-cycle ice is equal to or less than accretions obtained on the same propeller on an airplane flight tested in icing conditions and shown to have no appreciable loss in thrust.

D.3.2 The typical deicing boot manufacturer report also contains a caveat that it does not address propeller runback ice. A comparison of similarity to another propeller that was flight tested in icing conditions is usually done to address runback. Points of similarity would include propeller and deicing boot aerodynamic and thermal similarity, and similarity of the deicing timer, propeller revolutions per minute (rpm), and flight conditions. Note that metal and composite propellers have different thermal masses.

D.3.3 As a final qualitative check for both inter-cycle and runback ice on new airplane certification programs, airplane performance should be checked during flight tests in icing conditions.

D.3.4 The propeller installation, including spinner and cowl geometry, should be compared to previously tested installations in icing conditions. Changes that could allow moisture to reach the brush blocks should be avoided. Water reaching the brush block area of the propeller deicing system has caused brush block/slip ring hydroplaning and loss of power to propeller deicing boots.

D.3.5 If the proposed propeller is calculated to have higher efficiency than the existing, approved propeller, follow the guidance in paragraph D.2.1, *Effects of Increased Engine Power or Thrust*, of this appendix.

D.4 ENGINE INLET OR ACCESSORY INLET CHANGES.

Guidance for engine or accessory inlet changes is provided in section D.2, *Engine Changes*, above. Section 25.1093 applies to engine oil and accessory cooling inlets as well as induction inlets.

D.5 ANTENNAS, INSTALLATIONS, OR OTHER EXTERNAL MODIFICATIONS.

D.5.1 When antennas, cameras, fairings for such installations, or other external installations such as drain masts are installed on an airplane, the applicant should show that:

D.5.1.1 The predicted ice accretion does not contribute significantly to drag.

D.5.1.2 There is no ice-shedding hazard due to impact or ingestion on downstream structure, engines, or propellers.

D.5.1.3 There is no ice-related performance reduction of lifting surfaces.

D.5.1.4 There is no ice-related effect on downstream air-data sensors or ice detectors.

D.5.2 For paragraphs D.5.1.1 and D.5.1.2 above, the applicant may first conduct a very conservative, simple analysis. If the initial analysis fails, it can be refined to determine if it was overly conservative. The conservative analysis can assume the following:

D.5.2.1 The water catch area is the full frontal area of the installation.

D.5.2.2 Collection efficiency is 1.

D.5.2.3 No runback or evaporation of impinging water will occur.

D.5.2.4 The ice shapes on blade antennae will be similar to airfoils, and the shapes on low profile antennae will be single horn shapes.

D.5.3 The applicant should determine the critical icing condition, which should include the airplane holding in continuous maximum conditions. If the analysis shows a problem, then the applicant can accomplish one or more of following:

D.5.3.1 Determine realistic collection efficiency either with an ice accretion code or with the FAA Technical Report DOT/FAA/CT-88/8-1, *Aircraft Icing Handbook*.

D.5.3.2 Determine the real impingement limits by using an icing code, which may reduce the collection area.

D.5.3.3 Run the full configuration in an icing code to determine if the installation is in a shadow zone.

D.5.3.4 If drag is a problem, run an ice accretion code to determine a more realistic ice shape.

D.5.4 The applicant should conduct flight tests in measured natural icing or with simulated ice shapes to determine if the ice accretions will have any detrimental effects if any of the following conditions exist:

D.5.4.1 The installation is upstream of air-data sensors or an ice detector.

D.5.4.2 The installation is on a lifting surface.

D.5.4.3 The installation could create a wake on a lifting surface. As an example, if an external modification is large enough (e.g., dish antenna), it may interfere with the flow field around the tail, and the susceptibility to ice contaminated tailplane stall may need to be addressed.

D.5.5 The one exception to paragraph D.5.4.2 above is fairings. For fairings, an analysis to show the impact on maximum lift coefficient, in combination with flight tests with no ice accretions, may be acceptable.

D.6 GROSS WEIGHT INCREASES.

If increased gross weight requires an evaluation of the airplane's handling qualities in icing conditions, the effect on ice accretions from the associated change in airplane attitude should be assessed. This assessment is necessary because impingement and icing limits on airfoils will change, for example, and accretion sites may form on the airframe that was previously free of ice.

D.7 CENTER OF GRAVITY ENVELOPE INCREASE.

Generally, the same guidance used for gross weight increases can be used for center-of-gravity envelope increases. The one exception is that a more forward center-of-gravity limit may make an airplane more susceptible to ICTS. For airplanes with unpowered, reversible elevators, or for airplanes with propellers, the applicant should address this by flight testing. An analysis may be acceptable for other airplanes.

D.8 FLIGHT ENVELOPE INCREASE.

D.8.1 If the applicant applies for an increase in maximum operating altitude, the applicant should demonstrate the following:

- The IPS operating pressures (for pneumatic systems) or temperatures (for thermal air) by dry air testing; and
- Stall characteristics with ice accretions.

D.8.2 The effect of increased cruise airspeeds and increased altitudes that could affect windshield ice accretion, and adequacy of the windshield heat, should be addressed.

D.9 TURBOPROP CONVERSION.

D.9.1 If the IPSs use engine bleed air for operation, the pneumatic lines may accumulate more water than the current unmodified type design. This water can subsequently refreeze and block the lines, resulting in failure of some or all zones of the pneumatic system. The applicant must show that the pneumatic deicing system will continue to function in icing conditions.

D.9.2 The pneumatic deicer operating pressure may also decrease at lower engine rpm. A minimum engine rpm for acceptable pneumatic operating pressure, which should allow for descent, should be established and published in the airplane flight manual.

D.10 MODIFICATIONS TO LIFTING AND CONTROL SURFACES.

If lifting and control surfaces are modified, critical ice accretions may have to be re-defined, especially if the changes affect operational wing angle-of-attack. This new definition includes pre-activation, inter-cycle, residual, and runback icing. Stall strips are collectors of ice and are an example of an area where leading edge ice accretions should be re-defined. If ice accretions change because of modifications, or if the modifications could affect control power or hinge moments, additional flight testing may be necessary. Refer to AC 25-25A for guidance on flight testing.

D.11 INSTALLATION OF VORTEX GENERATORS.

Depending on their location, vortex generators may accumulate ice. The applicant should provide data on expected ice accretions. Flight conditions to consider are hold, descent, and approach. Substantiation of the effects on stall speeds, stall characteristics, and stability and control should be provided.

D.12 MODIFICATIONS TO ICE PROTECTION SYSTEMS.

If IPSs are modified, critical ice accretions may have to be re-defined. This new definition would include pre-activation, inter-cycle, residual, and runback icing. If the critical levels of ice accretions are changed, or if the modifications to the IPSs could affect control power or hinge moments, the applicant should perform flight testing with simulated ice accretions. AC 25-25A provides guidance on flight testing.

Appendix E. Capabilities of Engineering Tools for Compliance with Part 25, Appendix O Requirements

E.1 ASSESSMENT OF ENGINEERING TOOL CAPABILITIES.

E.1.1 This appendix is the result of a 2009 evaluation of engineering tool capabilities for predicting Appendix O ice accretions and icing effects. This appendix provides an assessment of the engineering tool capabilities based on their state of development in 2009. In the main body of this AC, for purposes of plain language, the term supercooled large drop was spelled out. In this appendix, however, because the term appears so frequently, its acronym, SLD, will be used.

E.1.2 Table E-1 of this appendix graphically illustrates results of an assessment of the capabilities of engineering icing tools. As described in the legend to that table, the capability of each tool for the various applications is classified as green, yellow, or orange. As discussed in the main body of this AC, reliance on available simulation methods combined with engineering judgment will be required for finding compliance with the requirements of part 25, Appendix O. Even though a simulation tool type may be classified as green, an applicant should ensure that the specific tool is appropriate for its application and is used in a conservative manner, including consideration of critical-case icing conditions. General and specific concerns that should be considered are discussed later in this appendix.

E.1.3 Section E.2 of this appendix provides guidance on the tools, their capabilities, and best practices for tool use with respect to Appendix O conditions. Section E.3 of this appendix discusses means of compliance for specific airplane components. Sections E.4, E.5, and E.6 of this appendix discuss means of compliance for each of the three certification options given in § 25.1420. Section E.7 of this appendix discusses means of compliance for air-data sensors and windshields (§§ 25.1323, 25.1325, and 25.773). Section E.8 of this appendix defines standard roughness levels.

E.1.4 While table E-1 illustrates the state of simulation capabilities as of 2009, we expect that capabilities will improve in the future. We encourage applicants and research agencies to develop and validate the engineering tools currently classified in table E-1 as yellow and red.

Table E-1. Assessment of Appendix O Engineering Tool Capabilities

		Unprotected Areas				Protected Areas					Detection Methods			Air Data Sensors	
		Wing	Tail	Radome	Non-lifting Surfaces (antenna, inlets, external modifications)	Thermal (protected area)	Thermal (Aft of protected area)	Mechanical (protected area)	Mechanical (aft of protected area)	Fluid Freezing Point Depressant	Visual Cues (Reference Surface)	Instrument (position or installation effects)	Instrument (performance)	Instrument (position or installation effects)	Instrument (performance)
FZDZ MVD < 40µm	Icing Tunnels	G	G	R *	G	G	G	G	G	G	G / Y *	G / R *	G	G / R *	G
	Codes	G	G	Y	G / R* *	G	R	R	R	G	G / Y* *	G	R* *	G	R
	Tankers	R	R	R	R	R	R	R	R	R	R	R	R* *	R	R
FZDZ MVD > 40µm	Icing Tunnels	G	G	R*	G	G	G	Y	Y	G	G / Y *	G / R*	G	G / R*	G
	Codes	G	G	Y	G / R* *	G	R	R	R	G	G / Y* *	G	R* *	G	R
	Tankers	R	R	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
FZRA MVD < 40µm	Icing Tunnels	Y	Y	R*	Y	Y	Y	Y	Y	G	R	R	R	R	R
	Codes	Y	Y	R* *	Y / R* *	Y	R	R	R	Y	Y	G	R	G	R
	Tankers	R	R	R	R	R	R	R	R	R	R	R	R	R	R
FZRA MVD > 40µm	Icing Tunnels	R	R	R*	R	R	R	R	R	R	R	R	R	R	R
	Codes	Y	Y	R* *	Y / R* *	Y	R	R	R	Y	Y	G	R	G	R
	Tankers	R	R	R	R	R	R	R	R	R	R	R	R	R	R

LEGEND — Updated FEB 2009

Green (G)	This testing capability exists today and is suitable to be an element of a means of compliance, or is readily achievable based on current experience.
Yellow (Y)	This testing capability is possible, but has not been demonstrated, or there is limited or no validation.
Red (R)	This testing capability is unknown, or does not currently exist.
*	It may be possible to test small-scale installation effects, but large-scale installations are not currently feasible.
* *	Current 2-D capabilities exist with large droplet effects, but limitations exist in the use of 3-D codes for simulation of Appendix O effects.

E.1.5 This evaluation of icing test tool capabilities is predominantly based on assessment of National Aeronautics and Space Administration (NASA) LEWICE codes (2-D and 3-D), the NASA Icing Research Tunnel (IRT) facilities, and existing icing tanker information such as SAE ARP5904, *Airborne Icing Tankers*. International icing simulation codes and facilities were considered where information was available. The US Air Force icing tanker that was used for SLD investigations on select commercial airplanes during the 1990s is currently not operational, and its capabilities were not assessed.

E.1.6 The main body of this AC states that flight testing in natural Appendix O icing conditions should not be necessary if at least two methods of predicting Appendix O ice accretions are shown to provide similar results. Table E-1 of this appendix illustrates that, for some Appendix O conditions, few of the engineering tools are classified as green or yellow for use as a means of compliance. Radomes, for example, have no engineering tools classified as green. In other cases, such as areas aft of protected areas, there is only one simulation tool that is classified as green.

E.1.7 For testing in freezing rain (FZRA), there are very few engineering tools classified as green. This would indicate that the primary method for showing compliance available at this time appears to be flight testing in natural Appendix O icing conditions. In some cases, engineering judgment may allow other methods of compliance, even though not validated, when used in a fashion similar to that recommended for freezing drizzle (FZDZ). However, until the engineering tools become more mature, flight tests in natural Appendix O icing conditions will likely be necessary to achieve the confidence needed for certifying airplanes for unrestricted flight in Appendix O or a portion of Appendix O conditions (i.e., compliance with § 25.1420(a)(3) or § 25.1420(a)(2)).

E.1.8 For airplanes certificated to detect Appendix O icing conditions and safely exit all icing conditions (i.e., compliance with § 25.1420(a)(1)), it may be acceptable to use one tool alone, even if classified as yellow or red, without natural icing flight tests, if that tool is used in a conservative manner. In cases where there are two green tools available, the applicant should use both tools to verify results, as discussed in the main body of this AC.

E.1.9 The number of tests may be reduced through the use of conservative test methods and critical-point analyses. However, validation of the test methods should be accomplished until confidence is provided.

E.2 CAPABILITIES AND LIMITATIONS OF ENGINEERING TOOLS AND SLD MEASUREMENT INSTRUMENTATION.

E.2.1 Icing Tunnel Appendix O Simulations.

E.2.1.1 A tunnel that uses a single pressure source for spray bars cannot simultaneously produce the large and small drop distributions (bi-model distributions) defined in

Appendix O. However, NASA has developed a technique called "sequencing" that alternates large and small drop sprays to simulate Appendix O conditions.

E.2.1.2 When icing tunnels are used as an element of the means of compliance:

E.2.1.2.1 Scale effects must be considered for tunnel blockage effects for all tests.

E.2.1.2.2 For FZDZ with a median volume diameter (MVD) less than 40 µm, the cloud drop distributions in the IRT are similar to existing Appendix C calibrations.

E.2.1.2.3 If there are concerns about the bi-modal distribution affecting performance of IPSs, sequencing should be considered. Sequencing of freezing drizzle conditions has been demonstrated in the IRT for unprotected surfaces. The sequencing technique approximates drop distributions found in natural conditions (AIAA 2005-76, *Simulation of a Bimodal Large Droplet Icing Cloud in the NASA Icing Research Tunnel*). It results in rougher textures than Appendix C ice shapes.

E.2.1.2.4 Ice shapes in unprotected areas are generally considered critical from the perspective of producing the largest disruption to the airflow. With a large ice shape, details on the impingement limit characteristics, which may have a less critical effect, may not be essential. However, sequencing between large and small drop conditions may be necessary if standard sprays[2] do not produce the drop distribution appropriate for simulation of the conditions desired. In cases where the impingement limit characteristics are important, sequencing may be necessary.

E.2.1.2.5 In general, sequencing produces rougher textures than a standard spray.

E.2.1.2.6 Sequencing may not be an appropriate way to test thermal systems because the rate of mass flow per unit area (i.e., mass flux) of the incoming water is not the same for the small and large drop sprays.

E.2.1.2.7 If sequencing is used to test deicing systems, the ratio of sequencing time to shed cycles should be evaluated to ensure that sequencing does not inappropriately affect the ice shape.

E.2.1.3 Experimental tests of methods for designing subscale hybrid airfoils with full-scale leading edges to determine leading edge ice shapes for large-chord airfoil sections has been accomplished in icing wind tunnels.[3,4] These techniques have been used successfully for Appendix C icing conditions. Adapting them to icing tests for SLD

---

[2] The phrase "standard spray" method refers to using the IRT nozzles in off-design conditions to generate larger drops for SLD conditions.

[3] Saeed, Farooq, Selig, Michael S. and Bragg, Michael B., *Design of Subscale Airfoils with Full-Scale Leading Edges for Ice Accretion Testing*, Journal of Aircraft, Vol. 34, No.1, 1997.

[4] Saeed, Farooq, Selig, Michael S., Bragg Michael B., and Addy, Harold E. Jr., *Experimental Validation of the Hybrid Airfoil Design Procedure for Full-Scale Ice Accretion Simulation*, AIAA Paper No. 98-0199, Reno, NV, January 12-15, 1998.

conditions requires evaluating the areas of interest for impingement analysis and analysis of the flow-field to determine if scale conditions aft of the leading edge can be met considering the compromises necessary in design variables on circulation, velocity distribution, and impingement characteristics. Although we anticipate that the hybrid airfoil design technique would be applicable for SLD conditions, such use has not been tested and validated to date.

E.2.2 **Computational Fluid Dynamic Tools.**

E.2.2.1 Computational fluid dynamic (CFD) tools—the "codes" referred to in table E-1 of this appendix—are used extensively in certification for Appendix C conditions. CFD tools can provide valuable information on impingement limits, icing limits, ice size, ice shape, and ice thickness for Appendix O conditions. Some validation of collection efficiency and ice shapes has been accomplished for FZDZ; there have been no validation exercises for FZRA.

E.2.2.2 CFD tools have been devised to predict, using mathematical calculation, ice accretion on an airplane in SLD conditions and the behavior of various types of IPSs as a result of those accretions. Besides being useful for assessing effects on protected surfaces, these tools can also account for the possibility of SLD ice impingement beyond the IPS limits, as well as for possible water runback. No current CFD method, however, can identify the break-up of water into rivulets, roughness formation, or ice sliding that may occur under these circumstances. Thus analysis of the regions behind those that are protected by IPSs requires some combination of CFD results, empirical data and test results (if available), and engineering judgment. This usually consists of determining the extent of possible ice formation using some criteria from the computational analysis, such as ice extent, impingement limits, or some minimum ice thickness level. The resulting ice shape would include inter-cycle or residual ice on the protected region and ice formed aft of the protected region. This result is then combined with guidance on ice roughness levels, such as described elsewhere in this document, to produce a rough ice region that can be evaluated in wind tunnel testing or flight tests.

E.2.2.3 Information can be calculated for drop trajectories for evaluating sensor locations and potential visual cues.

E.2.2.4 Many non-lifting surfaces require testing with 3-D computer codes. At the current time, many 3-D codes do not have large drop effects (such as splashing and break-up). Even without large drop effects, however, 3-D codes can offer information on impingement limits. Although 3-D codes may generate physical models and correlations that can support analysis of large drop icing, the capabilities of performing analyses with 3-D SLD CFD tools have not yet been evaluated. There are codes that may have this potential, but no guidance can be offered at this time for their use.

E.2.2.5 Some codes have limited capabilities with short-chord geometries (e.g., antennas or struts) for Appendix C icing conditions. These limitations are expected to be similar for large drop icing and are typically addressed with empirical methods or icing tunnels. However, for non-lifting surfaces, conservative assessments may be acceptable, such as assuming drop impingement on the full frontal area, assuming the collection efficiency is one, and approximating the shapes appropriate for the temperature (glaze, rime, etc.).

E.2.3 **Icing Tankers.**

E.2.3.1 Icing tankers have been used extensively by some manufacturers for Appendix C icing certifications. Icing tankers typically have a limited plume size and have been used primarily for localized icing effects, such as ice shedding, and for assessing the thermal performance of anti-ice systems.

E.2.3.2 Current tankers do have some limited capabilities to produce freezing-drizzle-sized drops, but they cannot produce the distribution effects. Current tankers do not produce freezing rain distributions either, and the feasibility of producing such conditions is likely limited by drop break-up (due to deceleration effects) and the ability to sub-cool the large drops within a workable flight envelope. Additionally, drop sorting effects are likely because of higher fall rates of large drops within an Appendix O distribution.

E.2.4 **Instrumentation.**

E.2.4.1 When making in situ measurements of Appendix O conditions, it is important to note that technology to make such measurements is rapidly changing. It is essential to consult experts in all phases of the measurement program, including those aware of the latest problems and strengths of each probe. Applicants should use instrumentation suited to the task. Instrumentation must be mounted in appropriate locations on the airplane, where the measurements are not affected by the airflow. For certification purposes, the instrumentation must be calibrated. An often overlooked aspect of a measurement program is the need to calibrate the instruments. Appropriate software and analysis techniques are also essential because complicated algorithms are often needed in the analysis.

E.2.4.2 Instruments are required to measure particle concentrations as a function of size over the complete size range—2 µm to at least 1,500 µm—including cloud drops and precipitation drops. This may require more than one probe. Liquid water content (LWC) and ice water content (IWC) measurements obtained by integrating 2-D images from spectral measurements generally have larger errors than those obtained from probes specifically designed to make such measurements. Consequently, it is recommended that probes designed to measure LWC, and if necessary IWC, be used directly, recognizing that some hot-wire devices detect larger drops (>50 µm) with reduced efficiency. Mixed phase clouds can occur frequently, so it is necessary to be able to discriminate between ice and liquid particles, especially for sizes larger than 50 µm, so that ice particles are not incorrectly identified as SLDs. For detect-and-exit airplanes (those certifying to § 25.1420(a)(1)), it may not be necessary to measure IWC directly; but for airplanes using natural icing SLD flight tests to certify for a portion of Appendix O (§ 25.1420(a)(2)) or for unrestricted operations (§ 25.1420(a)(3)), IWC must be determined in order to assess the SLD conditions.

E.3 COMPONENT EVALUATIONS.

E.3.1 Lifting Surfaces.

E.3.1.1 This paragraph is applicable to anti-icing systems aft of protected areas and to deicing systems both on and aft of protected areas.

E.3.1.2 For detect-and-exit airplanes (§ 25.1420(a)(1)) in freezing drizzle conditions, icing tunnels alone may be used to develop ice shapes, provided that the model appropriately represents the airfoil beyond the FZDZ icing limit. Roughness may be evaluated in icing tunnel testing and replicated on the ice shapes for flight testing. The standard spray2 method should be used for anti-icing systems because of the varying mass flux of incoming water associated with sequencing. For deicing systems, it is acceptable to use either the standard spray or the sequencing technique.

E.3.2 Radomes.

E.3.2.1 Most radomes are too large to fit into existing icing wind tunnels. Additionally, computational analysis of radomes typically would require 3-D codes. Many 3-D codes do not have large drop effects and if they do not, freezing drizzle ice shapes cannot be simulated. However, all 3-D codes have capabilities for testing impingement limits. Radome ice shapes have been developed in the past for Appendix C icing conditions using analysis and observed ice shapes from Appendix C flight tests (typically holding ice shapes).

E.3.2.2 For detect-and-exit airplanes (§ 25.1420(a)(1)) in freezing drizzle conditions, one method of compliance would be to modify Appendix C ice shapes to account for the larger impingement regions produced in FZDZ as predicted by the 3-D codes. You may use CFD codes to predict ice thickness. Ice roughness should be in accordance with the section E.8, *Standard Roughness Levels for Appendix O Ice Shapes*, of this appendix. The radome ice tested should reflect the total mass associated with the icing exposures for § 25.1420(a)(1) airplanes, which are defined in part II of Appendix O.

E.3.3 Non-Lifting Surfaces (Antennas, Enhanced Vision Cameras, Struts, Auxiliary Inlets).

E.3.3.1 For non-lifting surfaces that do not require use of 3-D codes, 2-D codes in combination with icing tunnels are available as a means of compliance. However, many non-lifting surfaces require the use of 3-D codes. At the current time, many 3-D codes do not have large drop effects, although some codes may have this potential.

E.3.3.2 For detect-and-exit airplanes (§ 25.1420(a)(1)), if the non-lifting surface is not critical from an engine ingestion or airframe damage perspective, 3-D codes may provide sufficient information for compliance. However, for more critical surfaces, until large drop effects in 3-D codes are validated, icing tunnels alone may be used to develop ice shapes.

E.3.4 **Ice Detection Methods.**

E.3.4.1 Different types of ice detection require assessment of their capabilities in large drop conditions, based on their sensing technology. Vibrating probe type ice detectors, which detect ice accretion on a probe through a decrease in the probe's vibration frequency, may experience increased response time in large drop exposures because splashing and aerodynamic forces, particularly in near freezing temperatures, can cause water to shed from sensing surfaces. This physical behavior may also occur with other types of probes.

E.3.4.2 While CFD can determine whether the large drops impact the ice detection surface, available CFD codes cannot accurately predict aerodynamic forces that cause drop shedding, or freezing fraction effects that may delay freezing. Therefore, use of CFD alone is not acceptable for showing that ice detectors function in large drop conditions. When possible, effects of installation position should be evaluated with a combination of codes and icing tunnels. Devices mounted on smaller surfaces could be assessed in an icing tunnel. However, if the device is mounted on the fuselage, and tunnel blockage effects would preclude a meaningful icing tunnel test, then CFD codes that adequately predict the shadowing and concentration effects may be used to verify that the equipment is properly located.

E.3.4.3 Because of the lack of engineering tools for FZRA, primary and advisory ice detectors used for compliance with § 25.1420(c) will require validation in natural large drop conditions to substantiate that the detectors function in all Appendix O conditions. However, if ground testing can be substantiated with both FZDZ and FZRA drops representative of Appendix O distributions and temperatures, then validation in natural large drop conditions is not needed. If visual cues are certificated as the primary means of compliance with § 25.1420(a)(1)(i), and the airplane is equipped with an ice detector system that is not required for compliance with § 25.1420(a)(1)(i) or § 25.1420(c), then the ice detector need not be tested in natural Appendix O conditions. Certification of visual cues for detect-and-exit airplanes is discussed later in section E.4, *Certification for Detect and Exit—§ 25.1420(a)(1)*, of this appendix.

E.3.5 **Air Data Sensors.**

E.3.5.1 Air Data Sensor Position Installation Effects.

When possible, applicants should evaluate the effects of air data sensor installation position with a combination of CFD codes and icing tunnels. Devices mounted on smaller surfaces could be assessed in an icing tunnel. However, if the device is mounted on the fuselage and tunnel blockage effects would preclude a meaningful icing tunnel test, then codes that adequately predict the shadowing and concentration effects are acceptable as the only method for compliance with installation location requirements.

E.3.5.2 Air Data Sensor Performance Effects.

E.3.5.2.1 Icing tunnels alone may be used to determine the performance of air-data sensors in Appendix O icing conditions in compliance with §§ 25.1323, 25.1324, and 25.1325. For sensors with collection efficiencies approaching “1,” if performance has been shown in FZDZ conditions, then a qualitative analysis based on water-catch ratios may be used for extrapolation to FZRA conditions.

E.3.5.2.2 If the Appendix C or mixed phase or ice crystal conditions are shown to be more critical for air data sensors than the SLD environment, the number of tests may be reduced. However, the test methods should be validated until there is confidence with the results. In some cases, such as that of wing leading-edge-mounted lift transducers, icing tunnel tests may still be necessary.

E.4 CERTIFICATION FOR DETECT AND EXIT—§ 25.1420(A)(1).

E.4.1 Detect-and-Exit Freezing Drizzle Less than 40 µm.

E.4.1.1 FZDZ conditions with an MVD less than 40 µm are similar to existing Appendix C distributions with the exception of a small percentage of the mass in drops larger than typical Appendix C conditions. As a result, many of the current Appendix C simulation methods can support compliance. The small percentage of large drops in this distribution can affect the impingement limits and increase the water catch.

E.4.1.2 If visual cues are used for compliance with § 25.1420(a)(1)(i), it may be possible to use codes in combination with icing tunnels to verify the visual cues. Visual cues should not be based on only one engineering method; a second, correlating method should be used.

E.4.2 Detect-and-Exit Freezing Drizzle Greater than 40 µm.

Where the capabilities of the tools available for FZDZ>40 µm are the same as for FZDZ<40 µm, the applicant may use similar means of compliance that are adjusted for the FZDZ>40 µm icing conditions. The tool capabilities are different for mechanical deicing system protected areas and areas aft of the protected areas.

Note: Icing tunnels are classified as yellow when used for testing for FZDZ>40 µm because use of the tunnels appears feasible but has not been demonstrated. Icing tunnel tests alone are acceptable for the development of ice shapes for deicing system protected areas and areas aft of the mechanically protected areas. Sequencing or standard distributions are acceptable, but the ratio of sequencing time to shed cycles should be examined.

E.4.3 Detect-and-Exit Freezing Rain (MVD<40 µm and MVD>40 µm).

E.4.3.1 The capabilities of the tools for FZRA are limited. To simulate accretions on unprotected surfaces and aft of protected areas, CFD codes may be used to determine the difference in impingement region between FZRA and FZDZ. The increase in impingement area can then be simulated using a standard roughness in that region. For areas where a ridge of ice may form, a simulated ridge may be developed using a height developed analytically based on local water catch. Ridge location could be developed from FZDZ tunnel tests, and the height would be modified based on the ratio of local water catch (determined with CFD) between FZDZ and FZRA.

E.4.3.2 Other Concerns.

E.4.3.2.1 Thermal Ice Protection Systems.

Analyses to assess water catch and melting/evaporation rates are acceptable for determining the capabilities of thermal systems in FZRA, provided that the analyses are based on the validated results of the system capabilities performed for Appendix C and FZDZ. Any additional ice that may form on runback ice shapes in FZRA should be accounted for by analysis of the runback volume. Potential roughness effects ahead of the runback should be addressed.

E.4.3.2.2 Mechanical Ice Protection Systems.

For assessing mechanical IPS performance in FZRA, it is acceptable to use the same pre-activation and inter-cycle and residual ice shapes as for FZDZ. The limits of accretion should be determined using CFD tools.

E.4.3.2.3 Validation of Visual Cues.

Use of qualitative analysis is acceptable for assessing whether visual cues used for FZDZ will function in FZRA conditions.

E.5 CERTIFICATION FOR A PORTION OF APPENDIX O—§ 25.1420(A)(2).

E.5.1 Current technology does not support distinguishing between FZDZ and FZRA in flight. For this reason, airplanes should not be certificated for compliance with § 25.1420(a)(2) based on the boundaries between FZDZ and FZRA. Certification with § 25.1420(a)(2) is discussed in the main body of this AC; however, there are concerns about the ability of applicants to define ice shapes which distinguish between the approved portions and the unapproved portions of Appendix O with the current simulation tools. As a result, certification for a portion of Appendix O will be challenging and will require close coordination with certifying authorities.

E.5.2 Certification for a portion of Appendix O that considers phase of flight (e.g., takeoff, holding), as discussed in paragraph 12.1 of this AC, may be feasible. Any method of certification for a portion of Appendix O should be included as part of the certification planning and will require approval from the appropriate certifying authority.

E.5.3 In cases where only one engineering tool or none has been validated as capable of simulating FZDZ or FZRA, the means of compliance should include flight tests in measured Appendix O icing conditions to verify ice accretions.

E.6 CERTIFICATION FOR UNRESTRICTED OPERATIONS—§ 25.1420(A)(3).

The use of simulation tools as described for detect-and-exit airplanes is also acceptable for showing compliance for airplanes certificated in accordance with § 25.1420(a)(3).

However, in cases where only one engineering tool (or none) has been validated as capable of simulating FZDZ or FZRA, the means of compliance should include flight tests in measured Appendix O icing conditions to verify ice accretions.

E.7 COMPLIANCE WITH §§ 25.1323, 25.1324, 25.1325, AND 25.773.

E.7.1 Compliance with §§ 25.1323, 25.1324, 25.1325, and 25.773 for Appendix C and Appendix O Conditions.

Analysis of exposures to Appendix C and Appendix O conditions should consider holding operations consistent with the applicable "Holding Ice" definition contained in part II of those appendices.

E.7.2 Compliance with §§ 25.1323 and 25.1324 for Mixed Phase and Ice Crystal Conditions.

Analysis of exposures to mixed phase and ice crystal conditions should consider the horizontal extents defined in the rules.

E.8 STANDARD ROUGHNESS LEVELS FOR APPENDIX O ICE SHAPES.

Ice shapes for part 25, subpart B, testing are typically based on icing tunnel tests or CFD computations or both. Current CFD programs do not provide roughness information. Roughness levels and aft extent of roughness for Appendix O ice shapes should be determined from icing tunnels or tanker testing, if the capabilities exist. However, when the empirical capabilities do not exist, the roughness levels (or equivalents) as defined in table E-2 below may be used. Note that roughness levels for Appendix C ice shapes are discussed in AC 25-25A.

Table E-2. Appendix O Icing Standard Roughness

Ice Type	Roughness Height (mm)	Percent of Surface Covered	Notes
FZDZ and FZRA, thin accretions; thickness < 3 mm (0.12 inch)	1.5 to 2 mm (0.06 to 0.08 inch) or 16 to 20 grit sandpaper	Particle density to cover 50% to 70% of total area	Use to simulate pre-detection, initial accretions, or roughness on computed ice shapes
FZDZ thickness > 3 mm (0.12 inch)	3 to 6 mm (0.12 to 0.24 inch) Mean particle size ~4.5 mm		Inter-cycle, residual, unprotected surfaces
FZRA thickness ≥ 3 mm (0.12 inch) and ≤ 6 mm (0.24 inch)			
FZRA thickness ≥ 6 mm (0.24 inch)	6 to 8 mm (0.24 to 0.31 inch) Mean particle size ~7 mm		

Notes:

1. The simulated roughness elements should approximate roughness elements observed in icing tunnels or natural icing. Smooth and spherical elements should not be used because they may result in non-conservative aerodynamic results.
2. For computed ice shapes, the roughness simulation should be extended aft to the limits of predicted accretion (where the ice accretion thickness is calculated as 0.015").

Appendix F. Acronyms

Table F-1. Acronyms and Definitions

Acronym	**Definition**
ACO	Aircraft certification office
AFM	Airplane flight manual
CFD	Computational fluid dynamics
CFR	Code of Federal Regulations
FZDZ	Freezing drizzle
FZRA	Freezing rain
ICA	Instructions for Continued Airworthiness
IRT	Icing research tunnel
ICTS	Ice-contaminated tailplane stall
IPS	Ice protection system
IWC	Ice water content
LWC	Liquid water content
MED	Mean effective diameter
MMD	Median mass dimension
MVD	Median volume diameter
NASA	National Aeronautics and Space Administration
RPM	Revolutions per minute
SAE	Society of Automotive Engineers
SLD	Supercooled liquid drops
STC	Supplemental type certificate
TC	Type certificate
TSO	Technical Standard Order

Advisory Circular Feedback

If you find an error in this AC, have recommendations for improving it, or have suggestions for new items/subjects to be added, you may let us know by (1) emailing this form to 9-AWA-AVS-AIR500-Coord@faa.gov or (2) faxing it to the attention of the Aircraft Certification Service Directives Management Officer at (202) 267-3983.

Subject: ________________________ Date: ____________________

Please check all appropriate line items:

☐ An error (procedural or typographical) has been noted in paragraph ______________ on page ____________________.

☐ Recommend paragraph _____________ on page ________ be changed as follows:

☐ In a future change to this AC, please cover the following subject:
(Briefly describe what you want added.)

☐ Other comments:

☐ I would like to discuss the above. Please contact me.

Submitted by: _________________________________ Date: __________________________